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Vol. 4. No. 3 | Pittsburgh, Pa. | March, 1931

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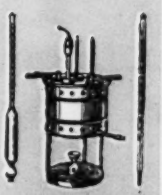

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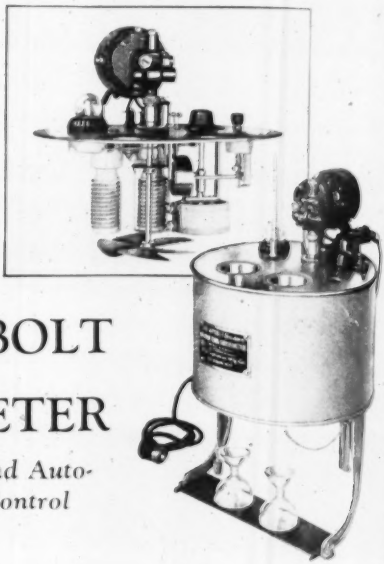

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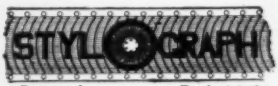

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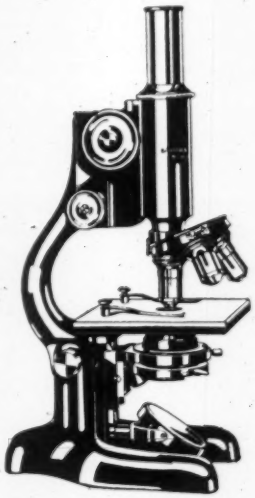

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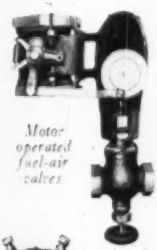

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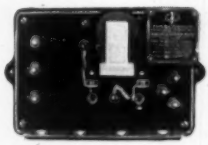

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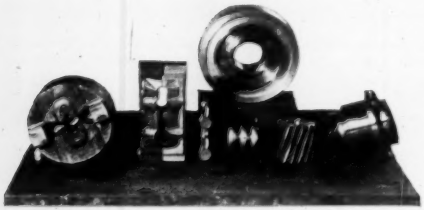

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Richard Rimbach, Managing Editor **M. F. Béhar**, Engineering Editor

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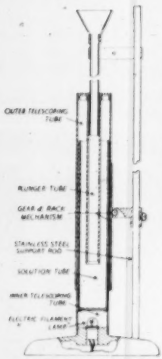

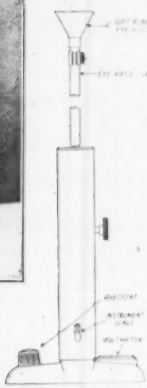

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AUTOMATIC CONTROL. A new 1931 Tycos catalog of instruments for canning, packing and preserving. Latest types of Tycos instruments for all canning applications are shown. Taylor Instrument Cos., Rochester N. Y.

BALANCES AND WEIGHTS. A booklet describing and illustrating various balances and weights of precision. Seederer-Kohlbusch, Inc., 149 New York Ave., Jersey City, N. J.

pH TESTER. The "Wulff" pH Tester, a simple, portable apparatus for rapidly measuring acidity and alkalinity. Pfaltz & Bauer, 300 Pearl Street, New York, N. Y.

CONTROLLERS. A circular describing how a progressive steel company controls galvanizing temperatures well within desired limits with potentiometer controllers. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

CURVE TRACER. Circular 7460 illustrates an easily-operated curve tracer for studying wave form. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

BAUSCH MEMORIAL BRIDGE. This folder describes the life of John Jacob Bausch, the founder of the Bausch & Lomb Optical Company, and to whom the city of Rochester recently dedicated its newest and finest span across the Genessee river. Bausch & Lomb Optical Co., 637 St. Paul St., Rochester, N. Y.

MOISTURE METER. Bulletin 1007 describes the TAG-Heppenstall Moisture Meter, which in a few seconds sorts out wet stock or indicates moisture content accurately. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

TESTING SET. Leaflet SH 4074 describes a complete testing set for starter and lighting motors and magnetos. Herman H. Sticht & Co., New York, N. Y.

RELAYS. Types CO and CR relays are described in circular L-20514. Westinghouse Electric & Manufacturing Co., Newark, N. J.

VIBROSCOPE. A circular describing the Vibroscope Model-3 which is a simple portable instrument for studying the behavior of rapidly moving machine parts, while actually in motion. Electrocon Corporation, 6 Varick St., New York, N. Y.

ELECTROMETER. Bulletin No. 330 describes and illustrates the Compton quadrant electrometer, which is a sensitive modification of the original quadrant electrometer with adjustable electrostatic control. Rubicon Company, 29 North Sixth St., Philadelphia, Pa.

MEASURING INSTRUMENTS. A circular describing the Alnor instruments used for observing temperature. Illinois Testing Laboratories, Inc., 141 W. Austin Ave., Chicago, Ill.

PYRO-PROD. Bulletin No. 526 describes the Alnor Pyro-Prod used in galvanizing pots, core ovens, annealing and heat-treating furnaces and printing plants. Illinois Testing Laboratories, Inc. 141 W. Austin Ave., Chicago, Ill.

PYROMETER. Bulletin No. 523 describes the Alnor wall-type pyrometer. Illinois Testing Laboratories, Inc. 141 W. Austin Ave., Chicago, Ill.

TESTING SET. Circular 5600-G describes the improved insulation testing set for laboratory use. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

TEST SWITCH. Leaflet L-20502 illustrates and describes the construction, application and distinctive features of the switch. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

REGULATORS. Bulletin 18,000 September 1930 edition describes the Tyme-Cycle Regulator. Taylor Instrument Cos., Rochester, N. Y.

TYCOS. The January 1931 issue of this publication which is published quarterly, contains the following articles: Harnessing the Sun for Healing the Sick; A Page of Clouds; Reinforcing Weather for Crop Culture; What was the Highest Temperature today; Radio Address Tailor-Made Weather for Trains; Jack Frost is Nature's Strong Man; etc. Taylor Instrument Cos., Rochester, N. Y.

USTCOGRAPH. A circular describing the ustcograph used for recording every movement of your truck, and the exact moment it occurs. U. S. Fare Recording Co., Inc. 511 W. 54th St., New York, N. Y.

KVA DEMAND METER. Bulletin No. 80 describes the type S KVA Demand Meter which is an addition to the instruments available for the measurement of electrical loads. Sangamo Electric Co., Springfield, Ill.

SURVEYING INSTRUMENTS. A booklet describing and illustrating the various surveying instruments. Carl Zeiss, Inc., 485 Fifth Avenue, New York, N. Y.

TACKISCOPE. A circular describing the tackiscope developed to enable an observer to study the successive phases of varying motion through the projection of interrupted light flashes upon the subject. Robert Donner, 423 M. & T. Building, Buffalo, N. Y.

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GRAPHIC. No. 131 of this publication is entitled "Watching the Watts with Graphics" by C. R. Hepner of the Willard Storage Battery Co. Esterline-Angus Company, Indianapolis, Ind.

GAS SERVICE JOURNAL. Vol. V, January 1931 contains the following articles: Evaluating the Industrial Load and How to Get it; Waterloo, Iowa, Solves Holder Capacity Increase Complications; Gas Utility Revenues Aggregate $519,691,351 in First Ten Months; Isle of Romance First Gas City in Texas; Old Gas Wells Become Tanks for Steel Firm; Natural Gas Finds Best Market Among Industrial Customers. Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

POLISHING MACHINE. A circular describing a metallographic polishing machine which is easy to operate. It enables the operator to change polishing disks quickly and easily by merely lifting one disk from the motor shaft and substituting another. The Cincinnati Electrical Tool Co., Madison & Edwards Rds., Cincinnati, Ohio.

MICROSCOPE. Pamphlet No. 1180 describes the new Binocular Research Microscope used for convenience and comfort during continued observation. E. Leitz, Inc., 60 East 10th St., New York, N. Y.

DRIVE UNITS. A circular describing the drive units available, like the control of which they are a part, for use on any type of fan damper, fuel-feeder, etc. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

OHMMETER. Bulletin No. 11 describes direct current volt-ohmmeter used for continuity testing, or for reading voltages up to 600 volts, direct current. Roller Smith Co. 233 Broadway, New York, N. Y.

INSULATION TESTER. Bulletin 1280-S describes a "Super-Meg" insulation tester for testing transformers, bushing, insulators, etc. and high-tension equipment having insulation resistance higher than 200 megohms. James G. Biddle Co., 1211 Arch St., Philadelphia, Pa.

WATER WORKS JOURNAL. The January 1931 issue of this publication contains the following articles: The Water System of Nitro, West Virginia; Maintenance and Testing of Meters as Practiced in Los Angeles; Alpine Dam; Water Meter Design; Hydraulically Speaking; California's Bottled Waters. Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

PYROMETER. A circular describing a potentiometer pyrometer which is rugged enough to withstand hard industrial usage. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

40 YEARS OF INDUSTRIAL SERVICE. This booklet is the first piece of institutional literature gotten out by Tagliabue Mfg. Co. in 162 years. It describes and illustrates their various departments and the instruments made therein. C. J. Tagliabue Manufacturing Co., Park & Nostrand Aves., Brooklyn, N. Y.

EXPERIMENTER. The January 1931 issue of this publication contains an article by Robert F. Field, entitled, "Field-Intensity Measurements." General Radio Company, Cambridge A., Mass.

MEASURING INSTRUMENTS, LAMPS, FREQUENCY METERS. Bulletins No. 1270, 1275 and 1280-P contains descriptions of these various instruments. James G. Biddle Co. 1211 Arch St., Philadelphia, Pa.

LABOR SAVING. A circular entitled "Reducing Labor Losses in Modern Industrial Plants." Esterline-Angus Co., Indianapolis, Ind.

PROTECTIVE RELAYS. An 88 page paper book entitled "Silent Sentinels" with illustrations and descriptions of protective relays for A-C and D-C Systems. Westinghouse Electric & Mfg. Co., Newark, N. J.

INSTRUMENTS. Catalog 211 contains 186 illustrated and descriptive pages of instruments, relays and electronic devices. Westinghouse Electric & Mfg. Co., Newark, N. J.

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EDITORIAL COMMENT

New Instruments—Quantity, Quality and Quickness

The troublous, critical year 1930 has passed into history, but the feeling of tightness and tenseness which characterized that period is still with every engineer, every laboratory technician—as well, indeed, as with every business man and every paterfamilias.

Historians will now proceed to collect, arrange, and interpret. Their searchlight will as usual play on the major industries, and undoubtedly will pass over the instrument industry. Their attention will dwell on the larger phenomena, and undoubtedly will pass up Instrumentation.

Wherefore the duty incumbs on this magazine to point out one item of good that was blown by an otherwise ill wind. We refer to the good that was accomplished by the Instrument Industry.

It is as yet too early to integrate the recent progress in all its ramifications. Time's perspective is needed. But we cannot refrain from jotting down three significant facts which have thrust themselves to the editor's attention. These facts have to do with the remarkable number of new instruments developed by the instrument industry in 1930, with the improvements in quality noticeable in most of the new instruments, and with the rapidity with which scientific discoveries were translated into practical forms during that period . . . Quantity, quality and quickness.

As to quantity—At no time did the mail bring the editor a greater volume of manufacturers' announcements of new instruments, than in the closing months of 1930. Our readers may have noticed that our February New Instruments section contained no fewer than *thirty-eight* separate items. In this month's issue we have fifteen.

As to quality—The outstanding fact, in our opinion, is that many manufacturers have adopted the practice of stating specific figures of limits of error, tolerances, applicability, service life, frequency of adjustments, etc. In every case these data are not only much more satisfactory than the old-time advertising language, but they indicate a degree of excellence far beyond the normal requirements of users. In other words the quality of the newer instruments is so much higher than the minimum demands of science, industry and education, that manufacturers feel perfectly safe in laying down all cards.

As to quickness—we shall report only one incident, but it is nothing short of dramatic: The same mail that brought us the scientific calculations recently worked out by a group of research specialists in creating a new instrument also brought us a manufacturer's announcement of such an instrument in its industrial form! Incredible? Perhaps it may be to some, but it nevertheless is true. Here are the two pieces of evidence:

(1) In the February number of *The Review of Scientific Instruments* appears a paper by A. W. Simon, L. C. Kron, C. H. Watson and H. Raymond (see our Current Literature Review section) on a new principle of recording the *concentration* of dust or smoke particles—the use of a light-source and a *thermopile*. This combination, as used for that purpose, is new.

(2) Leeds & Northrup Circular 6591-G entitled "Announcing the New L & N Smoke Recorder" (See New Instruments Section).

"Believe it or not" as Ripley says, these two items came—as we mentioned—in the same mail.

That is to say, American alertness and enterprise, instead of relaxing in the year of depression, were intensified—at least in the instrument industry—to such an extent that the same time required for the appearance of the approved official scientific paper in the columns of our esteemed contemporary *The Review of Scientific Instruments* was required by a wide-awake manufacturer to bring out the industrial instrument itself.

We believe that such an achievement is on a par with the production of the Liberty Motor and other miracles of war-time speeding-up.

We not only believe, but we know, that this is typical of the attitude of the entire American instrument industry throughout the fighting year of 1930.

And we are confident that this "war time" alertness will not suffer any decline now that prosperity is hastening back.

We Lose Mr. Schroder.

Few are the men, and fortunate, who can so dovetail their time as to fill two jobs well. When both jobs require a great deal of both time and effort, then it comes down to whether health will hold out. Mr. Arthur Schroder made an enthusiastic and successful start on "The Handbook of Laboratory Instruments and Apparatus" without neglecting his duties as Director of Technical Service of the Fisher Scientific Company, but it became necessary for him to give up either his regular job or the preparation of the book.

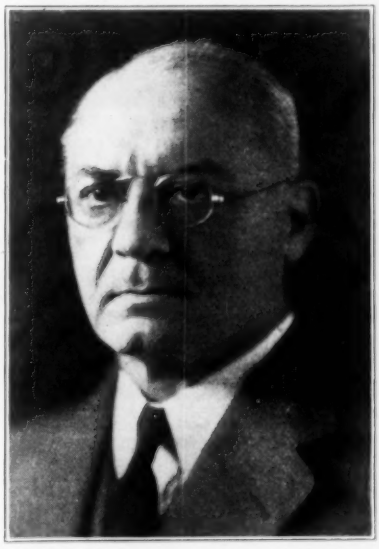
We regretfully bow to the inevitable; but assure our readers that the serial publication of the laboratory instruments handbook so well begun by Mr. Schroder will be resumed beginning with the next issue. Our readers will no doubt share our regret at losing Mr. Schroder and join us in wishing him continued and even greater success in his regular work, which has already attracted many favorable comments.

Instrument Springs and Diaphragms

The article on this subject by our engineering editor, on page 173 of this issue, was written as part of the chapter on Pressure Measuring Instruments in his Handbook; but we decided to print it under a separate heading in order to attract to it the attention that it deserves. It contains a number of surprising statements but they are thoroughly substantiated, for Mr. Béhar spared no effort, in the last few months, to gather his evidence. It is surprising, for example, that instrument manufacturers should admit a total lack of information on certain elastic and inelastic properties of certain all-important instrument parts; but this is explained by the fact that *no one* has quite successfully "isolated" these elusive properties and studied them in various spring materials and in variously shaped specimens, each by itself without the influence of other properties. It is now known that there are a number of these properties—so great a number that the text-books on

mechanics and on materials must be revised. The managing editor, who is a lecturer in metallurgy at the Carnegie Institute of Technology and editor of METALS & ALLOYS, respectfully recommends to instrument manufacturers and to all those interested in the improvement of instruments that depend on springs and diaphragms, that they should not only take a lively interest in the investigations mentioned in Mr. Béhar's compilation and submit specimens to the research groups (as some are doing), but that they should undertake specific research projects coordinated with the major investigations under way. That the results would be of practical benefit is shown by the example cited by Mr. Béhar, of the amazing improvement recently made in the accuracy of some aneroid instruments, by reducing the hysteresis effects through the application of lessons taught by Research.

Author of Instrument Book Receives A.S.M.E. Honor



At the recent Annual Meeting of the American Society of Mechanical Engineers the Melville Medal was presented to Professor Herman Diederichs and to William D. Pomeroy as co-authors of the paper on "The Occurence and Elimination of Surges from Oscillating Pressures in Discharge Lines from Reciprocating Pumps." The Melville Medal, established in 1914 by the bequest of Rear-Admiral George W. Melville, honorary member and past-president of the Society, is for an original paper or thesis of exceptional merit. Professor Diederichs is Director of the Department of Experimental Engineering in the Sibley School of Mechanical Engineering at Cornell University and will be remembered by the readers of INSTRUMENTS as co-author (with Associate Professor William C. Andrae) of "Engineering Instruments" which was reviewed in our September issue and which is the most complete book on this subject that has ever been published.

INSTRUMENTS BOOK SHELF

The books reviewed in this section can be supplied by the Instruments Publishing Company.

EIN BEITRAG ZUR DYANMISCHEN UNTERSUCHUNG VON BRUECKEN. *H. Marnet*. Doctor-Engineer thesis. Technische Hochschule Darmstadt. Feb. 1928. Paper, 6 x 8¼ inches, 57 pages.

By the use of an unbalanced mass, at varying speeds, rotating and acting on a beam through a spring, and optical methods of measurement of the vibrations set up, the resonant frequencies of a beam about 9½ feet long, suspended in different ways, and loaded with various loads was studied in the laboratory to test the method.

Similar measurements were made on a bridge over the Main at Klein-Anheim. This was loaded by a railway car and the rotating unbalanced mass was driven by a portable gasoline engine, dynamo and motor. Preliminary calculations indicated that the bridge would have a natural period of vibration of 315 per minute. By measurement, with a load of 660 lbs. the period was 336 per minute, and with one of 41,500 lbs., 302.5 per minute. Various constants are figured from these values. It was concluded that the method was satisfactory for dynamic study of bridges and that it could readily be refined to give a precision of 1%.—H. W. Gillett.

Hand- und Hilfsbuch zur Ausfuehrung Physikochemischer Messung, By C. *Drucker*. 5th Edition of the Ostwald-Luther Handbook. Akademische Verlagsgesellschaft, Leipzig, 1931. Cloth 6 x 9½ inches, 979 pages. Price 52 RM.

The first edition of Ostwald's handbook was issued in 1893 and has been used by many generations of college students. The fourth edition came out in 1925. While all chapters have been revised and expanded by Drucker and a group of able collaborators, the chief addition is in regard to the use of electron tubes.

Drucker points out that many old methods of and devices for physicochemical measurements are as worthy of description and use as some more modern and complicated ones, and in fact, are often more simple and much cheaper. Hence a large part of the book is not essentially different from the old Ostwald-Luther the reviewer used 25 years ago.

The field covered is so very wide that a detailed coverage would be out of the question. Drucker has wisely chosen to deal with principles and with the simpler types of apparatus rather than to cover highly refined and specialized equipment. Fairly full references are given, through which more detailed information can be found, but on the whole the handbook seems designed to cover such apparatus as is required in undergraduate laboratory courses in physicochemical measurements rather than in advanced research work. In the treatment of calorimeters, thermostatic control, high vacua, and laboratory electric furnaces, for example, necessary details on special apparatus necessary for refined work may be traced only through the footnote references, if at all. The type of equipment built up chiefly by the glass blower is rather thoroughly dealt with, but mechanical and electrical equipment such as chronographs, oscillographs, potentiometer controllers, etc., scarcely receives mention. The physical chemist dealing with aqueous solutions will find a great deal of value in the book. The physical metallurgist will find something of value but will not find information on a very large proportion of the types of measuring equipment he needs for advanced work. A notable exception is, however, the fact that the elements of X-ray spectrography are discussed.

Within its limitations, the volume is a very valuable handbook.—H. W. Gillett.

Handbuch Der Wissenschaftlichen Und Angewandten Photographie Edited by *Alfred Hay*. Vol. VIII. Farbenphotographie, *L. Grebe, A. Huebl, E. J. Wall*. Verlag von Julius Springer, Vienna, 1929. Paper 7x9½ inches. Price 24 R.M.

In spite of its seeming remoteness from the field of measuring technique this volume on color photography which concludes the series of treatises on scientific and applied photography as the eighth volume, contains much of interest on measurements which lie, of course, entirely in the field of optics. It is interwoven in a masterly clear and yet concise treatment of light and color; subjective and objective impressions of light, the functioning of the eye, sensitiveness, sharpness; the different spectrums, spectroscopy, color mixtures, color geometry, all is treated in an extraordinary lucid manner, especially the mathematics of the subject which are always kept very simple. For the measuring technician the description of photometers, spectroscopes, testing arrangements for the comparison of colors, and the definition of body colors by the fundamental colors will be especially interesting.

The greatest part of the book, almost half of it, is devoted to the third part, practical color photography, written by the late E. J. Wall of Wollaston, Mass. Color filters, sensibilization, the different processes of color reproduction are fully described and recipes for developers, sensitizers, baths, etc. are profusely given. Bibliographical references and especially patents pertaining to the subject make this book as complete as can be desired. If there is one regret it is that apparently lack of funds did not permit the reproduction in colors of the spectrum tables which, with the present state of the art, would have certainly enhanced its value. But nevertheless, this compendium will be the standard handbook for all workers in this field for a long time to come.—Max Hartenheim.

Storage Batteries. *George Wood Vinal*. John Wiley & Sons, Inc., New York, 2nd edition, 1930. Cloth, 6¼x9¼ inches, 427 pages. Price $5.00

The storage-battery industry and those concerned with storage batteries are particularly fortunate in having this volume available for reference. The second edition is a worthy successor to the first, which appeared in 1924. In general, the plan and scope are practically the same as that of the first edition. The text has been somewhat revised and brought up to date, some further experimental work has been included, and a few additional paragraphs have been added. The book is a very satisfactory description of the present status of storage batteries. There is no mention of new principles or possible future developments.

Much of the subject matter has been provided by the studies carried on by the author at the Bureau of Standards. He has shown a keen appreciation of the practical side of battery construction, use, and testing, and has included enough theory to allow for an intelligent discussion and understanding of his subject. This book would serve equally well as a text for the student, a reference for the battery chemist or engineer, or as a manual for the battery service station and ultimate users. A good bibliography is included.

Most of the book is devoted to the discussion of the lead-acid storage battery, although due mention is made of the Edison cell, its construction and characteristics. A complete description of the acid type battery is given in detail starting with the raw materials and including a careful definition of all terms and parts, a general discussion of up-to-date manufacturing methods, and much valuable information in regard to battery characteristics, methods of testing, and present-day uses. In addition there is a brief but sufficient and clear description of the theory and chemical and electrochemical characteristics of a storage battery, as well as a wealth of pertinent information in the form of tables and graphs. Special mention should be made of the author's work on battery testing. This work shows a clear understanding of the factors which influence battery value and which, if more generally appreciated, would react in favor of the better brands of storage batteries available in this country today.

Since no claim has been made as to the finality of statements and figures, there is no cause to criticize those few upon which there may be some difference of opinion. It is certain in any case that figures and curves do represent good average values. The book is highly recommended.—C. C. Rose (Reprinted from Industrial & Engineering Chemistry, July 1930.)

THE HANDBOOK OF INDUSTRIAL INSTRUMENTS

CHAPTER XI

Pressure Measuring Instruments

M. F. Béhar*

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9. Springs, Diaphragms, etc. and Their Properties

(Printed as a separate article. See page 173 this issue.)

10. Bourdon and Other Tube-spring Gages

This Section is descriptive. For principal characteristics see Tables IX, XVII, XVIII and XIX. For specifications, tests, adjustments, etc. see Section 15. For calibration methods see Section 2. For industrial accessories, features, etc. see Section 16. For properties of elastic members *alone*, see Section 9. For classification of errors of an elastic-member instrument *as a whole* see Section 13, heading (e).

This is the most important class of industrial pressure measuring instruments. It comprises all gages the primary element of which is a bent or coiled tube-spring of flattened cross-section. (This class comprises also the double-tube Bourdon gages.) To explain the principle would be an affront to our readers' intelligence; but on the other hand, to print even a summary of the mathematical treatment would mean too great a departure from the practical: it is believed that fewer than a dozen men in the U. S. have found it necessary to use the formidable formulas of Lorenz and other theoretical investigators. We even believe that the good old cut-and-dry method (plus Yankee ingenuity and minus the aid of higher mathematics) has determined the size and shape of 99% of the pressure-tube springs in the excellent gages on the American market.

Spiral and helical tube-springs differ only from the Bourdon tube in that while the latter makes part of one turn, the former have several complete turns so that, other things being equal, their free ends move over a greater distance in response to the same pressure increment or decrement. Another difference is that the connecting link need not be located at the end of the last turn but at any suitable place. This is quite an advantage in the case of *recorders* which have to be so calibrated at the factory that they will be accurate over the printed scales of interchangeable renewable charts. (But see how this can be done with a part-turn or ordinary Bourdon tube, in Fig. 302.)

The tube-spring gage is probably the pioneer and king of all industrial instruments—the simplest and most necessary, the humblest in some respects but the most important in many ways, and the mainstay of engineering since the dawn of the railroad and power age.

*Engineering Editor.

Fig. 288

Fig. 289

Fig. 290

Fig. 291

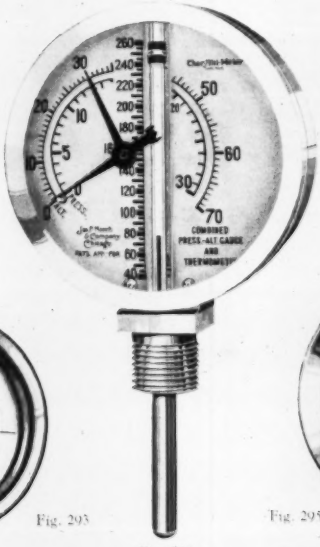


Fig. 294

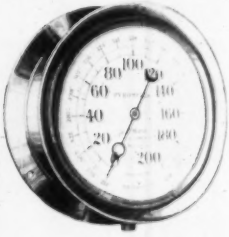


Fig. 292

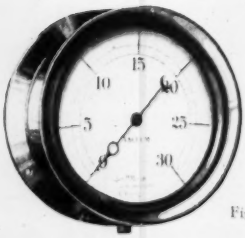


Fig. 293

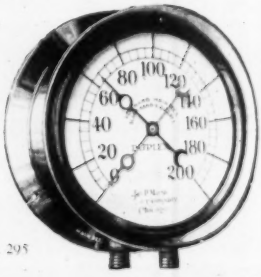


Fig. 295

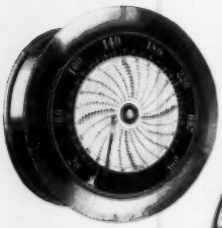


Fig. 296

Fig. 297

Fig. 298

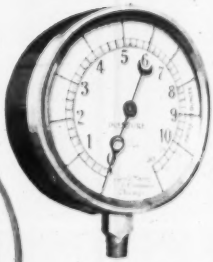


Fig. 299

STYLES AND GRADUATIONS OF GAGES FOR VARIOUS PURPOSES

Figs. 288-298 James P. March & Co.
Fig. 299 Tiffany Mfg. Co.

(a) Styles and Graduations

How many engineers are acquainted with the immense variety of elastic tube gages on the market? Perhaps some of those with consulting engineering firms or public service corporations, whose duty it is to specify gages for clients or subsidiaries and whose desks are piled high with instrument catalogs. Perhaps only some of those on the recently created gage standardization committee. A few notes, and illustrations, may serve to show what a variety is available, and to suggest ideas for specifying the appropriate gage for a given purpose.

Sizes—By "size" is meant, in most catalogs, the dial diameter, the round-chart nominal or actual size, or the full width of a strip-chart. Pending standardization we refrain (out of deference to the committee) from printing here a list of the present sizes, but it can be said that such a list would show unnecessary near-duplications, i.e., unnecessarily small differences between one size and the next larger and next smaller. These will no doubt be voluntarily eliminated. Few makers put out miniature tube-spring gages, and few make tube gages with dials smaller than 3½ inches. Miniature and small gages on the American market are mostly of the diaphragm class. The largest regular stock sizes of most makers are 12 to 16 inches, but giant illuminated "master" gages (of attractive appearance) are so frequently made up for boiler rooms that they may almost be called "standard," only the ornamental brackets being special architectural features.

On all industrial process applications where pressure is an important condition, it is false economy to specify gages so small that the operating men must walk over to read them closely. A large gage bears witness to the fact that the management considers pressure important; it saves steps; it can be read by men with sub-normal eyesight, and it generally proves a wise investment.

"*Styles*"—The usual style of scale subtends five-sixths of a full circle and is known as a 300-degree scale. Full-circle scales are seldom available. Obviously, the nearer the scale arc approaches a full circle, the longer will the scale be—the radius remaining the same. Obviously, too, increasing the radius by placing the figures on the inside and the divisions close to the edge of the dial (or close to the edge of the glazed opening) will also increase the scale length and hence the ease of reading. It so happens that most miniature gages have quadrant scales on their dials (Fig. 299) so that close reading is impossible. These are not really "indicating-*measuring*" instruments, however, but mere "indicators" which are neither designed nor expected to measure accurately beyond "too low" "normal" and "too high," where "normal" is anywhere between 40 and 60 percent of the scale range. At the other extreme we have the inspectors' and test gages with hand-graduated finely-divided 300° or 320° scales, needle-tip pointers traveling close to the surface of the dials, and other features suggesting a precision which their actual performance bears out splendidly—when they are not abused.

An idea of the variety of gage styles is conveyed by the group of eleven illustrations, Figs. 288 to 298—all taken from the catalog of one average American gage maker. (For almost every industrial purpose there are offered several makes and numerous models.)

The top row, for example, shows three different compound gages. Note their points of dissimilarity: The two gages, Figs. 288 and 289, have movements providing in each case uniform pointer travel for uniform pres-

sure increments, while Fig. 290 shows a gage with a movement that retards the pointer at both ends of the scale. The absolute ranges of these three gages are 0 to 75, 0 to 30 and 0 to 45 lb absolute but the dials are so scaled that when the pressure inside the spring equals that on the outside, the pointers read zero. The vacuum graduations, being as usual in inches of mercury, are almost exactly twice as close together as the pounds gage graduations (since 1 lb per sq. in. — 2.0367 in. Hg.) Note also that in Fig. 290, there are sixteen divisions between the figures on the pounds gage scale up to 5, so that this part of the scale is graduated in "pounds and ounces gage." Similarly the 0-5 lb portion of the scale in Fig. 291 is divided into eights, that is to say 2-oz. divisions. (Usually, pounds gage are divided decimally.)

There are on the market numerous gages scaled in pressure units and equivalents for temperature, altitude of water, etc. Fig. 292 shows what is usually called a "pyrometer steam gage" although, of course, steam temperatures are generally well within the range of thermometers and below the usual pyrometer ranges. Altitude gages, most commonly used for water heating systems, stand pipes, tanks, etc., are optionally graduated in feet of water only, or in pounds gage and equivalent feet, as is the case with the gage portion of the combination instrument illustrated in Fig. 294, which is especially designed for hot water boiler installations.

Another sort of combination instrument is shown in Fig. 295. It is known as a "Duplex" gage and finds its most widespread use on air brake systems. A duplex gage consists of two independent gage movements, usually of equal range, reading on the same dial.

Still another combination instrument is shown in Fig. 296. It combines an indicating and a recording gage and comes in three sizes, the chart diameters being 6¾ in., 8½ in., and 10 in.

(b) Construction

Reference is made to the *internal* construction. In the *indicating* gages this is generally divided into three main parts: (1) the socket; (2) the tube, and (3) the movement. The author personally prefers the construction consisting of a massive socket (also called "stem") in which one end of the tube (or tubes) is imbedded permanently and which also supports the movement. With such a design the movement is entirely independent of the case. There are, of course, good grades of tube gages in which the movement is supported by the back of the case, but with such gages the possibility always exists of external strains affecting the accuracy. The argument that since the graduated dial is generally fastened to the case, it is good design to fasten the movement to the case, does not impress the author in the least, for the reason that the *angular* component of relative motion of case-supported dial and socket-supported movement is always very slight, while relative motion of socket-supported spring and case-supported movement is *multiplied* and shows up as an *error of indication*. In the ideal construction the socket not only supports the tube and movement but also *positions* the dial, so that external strains, while they may *flex* the dial, cannot possibly *rotate* it and cause errors of indication.

In most respects Fig. 300 is the "typical" indicating Bourdon gage construction with socket-supported movement. Note, however, that the movement itself can be adjustably positioned, which is an unusual feature, the object of which is to make the gage rate adjustable. This subject of rate adjustment is discussed in Section 15, heading (c).

Fig. 300
(Consolidated Ashcroft Hancock Co.)

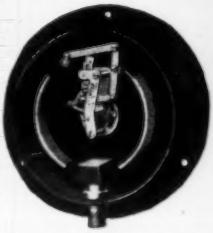


Fig. 301

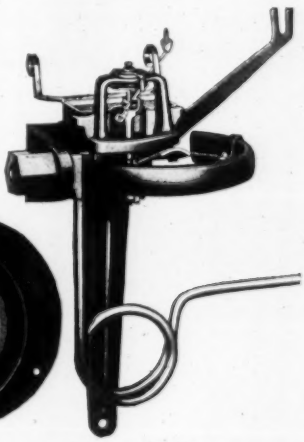


Fig. 302
(Esterline Angus Co.)

The usual arrangement of the two Bourdon springs in a double-tube indicating gage is shown in Fig. 301. Note that while one tube is longer than the other, it is neither exactly twice as long nor of any other proportion such that its natural period of vibration will be harmonic with that of the shorter tube at any frequency likely to be met in service. Thus a double-tube gage can usually withstand severe vibrations regardless of frequency.

The remaining illustrations, Figs. 302 to 307, bring out interesting construction features of recording gages: Fig. 302 a Bourdon form, Fig. 306 a spiral and the other four various helical forms of tubes.

Bourdon tube recorders are only available for high pressures, other pressure elements being more advantageous in practice for recording low pressures, vacuum, and particularly draft. Pen friction is one obvious reason.

In Fig. 302 note the adjustable connection for conveying the deflection of the tube to the pen arm from anywhere within about 1½ inch of the free end in order to make the gage rate uniform over a uniformly divided printed chart. Note also the vertical axis—this unit goes into the back of a strip-chart recorder like that shown in Fig. 313.

Fig. 303 shows a recording gage movement featuring a welded steel helical spring and a light but rigid phosphor bronze wire link made with a special bend on each end which forms a three-point bearing eliminating lost motion and minimizing wear.

The recording gage pressure-measuring element shown in Fig. 304 features a pen-arm rigidly fastened to the helical tube and represents the utmost simplicity to be found in high-grade instruments. This type of pressure unit is for service between 8 lb and 12,000 lb.

Fig. 305 shows a "magnified vacuum scale" type of recording gage pressure unit and is also of very simple construction, practically the same as Fig. 304 of the low range type, but it is restrained by a helical spring which gives a suppressed scale for the high ranges. This feature makes it possible to have a vacuum scale extending over a greater portion of the chart than could be obtained with other arrangements. It is specially desirable for use where wide open reading of vacuum scale is necessary without sacrificing sensitivity.

HELICAL TUBE AND SPIRAL TUBE MOVEMENTS OF INDUSTRIAL PRESSURE RECORDERS

Fig. 303
The Foxboro Co.

Fig. 304

The Bristol Co.

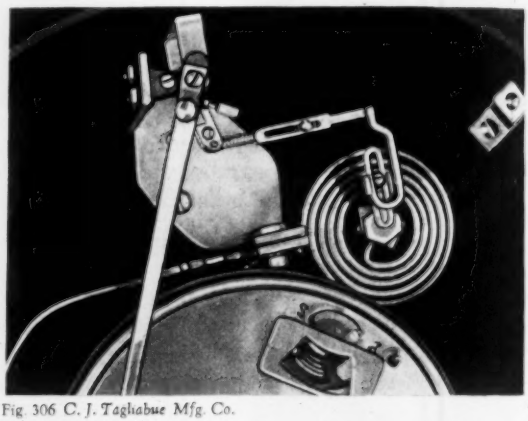


Fig. 306 C. J. Taglabue Mfg. Co.

Fig. 305

Fig. 307 Brown Instrument Co.

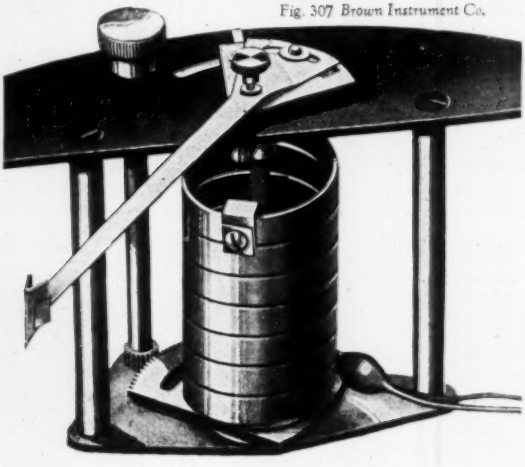


Fig. 306 is a photograph of a portion of a recording pressure gage which takes in the pressure unit—a spiral tube unit. Among the features of this design and construction are (1) a unique center-acting form of spring, and (2) a bi-metallic compensator for temperature fluctuations affecting the spring. See also description of Fig. 82 in the chapter on Temperature Recorders. (As a matter of fact the two photographs from which Figs. 82 and 306 were made are exact duplicates. A pressure-spring recording thermometer is essentially a pressure recorder and many of the remarks made in Chapter VII apply equally here.)

Fig. 307 shows plainly the method of locating the connection on the helical spring, also a unique method of easily changing the effective length of helix (see knob, pinion and sector). The helical tube shown is made of phosphor bronze and will stand a considerable overload without damage. It is also said by the maker that even in the case of a permanent error caused by an overload greater than 30%, the instrument may be successfully re-calibrated. "With the usual helix, however, the overload will have done permanent damage and the helix will continue to yield and continually read lower and lower, since the error cannot be compensated for." We may assert, nevertheless, that with recent improvements the "usual" helical springs of practically all high-grade gages are unimpaired by loads in considerable excess of their scale ranges.

(c) Tubes

Tubes are made of special alloys, mostly according to gage makers' specifications, sometimes according to large users' specifications. It seems best to leave this entirely up to the makers, because the desired elastic and endurance properties depend not only on percentages of elements in an alloy but on its treatment. In spite of the scarcity of exact and formulated knowledge of elastic, "fatigue," temperature and corrosion properties, decades of experience have taught the gage makers more kinks than users imagine: the author knows of tubes subjected *by an instrument maker* to secret processes that metallurgists had declared "impossible," with results in tube spring performance that could not be attained by following a large purchaser's detailed specifications—even if such purchaser were to be the U. S. government. The way things are now, secrecy seems necessary, but when patents and formulas are pooled, *all* Bourdon and other tubes will be good; some of course will be superlatively excellent but none will be poor; and the element of luck will have been largely eliminated.

(d) A. S. M. E. Initiates Gage Standardization

In December 1930, the organization meeting of the *Sectional Committee on the Standardization of Pressure and Vacuum Gages* (sole A. S. M. E. sponsorship), was held in New York with an attendance of 23 members representing 21 organizations. This committee will undertake the standardization of the *indicating* type of pressure, vacuum, and compound gages, nomenclature and definitions, requirements of accuracy, methods of expressing accuracy; methods of testing, specifications; rules for installation and use; gage sizes and mounting dimensions; connections and gage cocks, size, etc.; capacity ratings and ranges; continuous working capacity; graduation, markings, and space for trade mark and name plate, etc.; indicator hands, bushings, and micrometer adjustment; stop pins; and bezel rings and their attachment.

11. Diaphragms, Bellows, etc.

This Section is descriptive. For principal characteristics see Tables IX, XVIII and XIX. For specifications, tests, adjustments, etc. see Section 15. For calibration methods see Section 2. For industrial accessories, features, etc. see Section 16. For properties of elastic members *alone*, see Section 9. For classification of errors of an elastic-member instrument as *a whole* see Section 13, heading (e).

This class comprises a great variety of forms of pressure measuring elements, which divide themselves along two lines:

One classification is into (a) elastic diaphragms and bellows not supplemented by springs, and (b) highly flexible diaphragms and bellows supplemented by springs. This latter group tapers off into the class covered in Section 12, namely the membrane or loaded slack leather instruments.

Another classification is into (a) diaphragms—flat and corrugated, and (b) bellows. Under diaphragms we will not consider here the element variously called capsular spring, cell, box, etc., although it really is a double diaphragm, but on account of its importance we reserve it for Section 13.

(a) Diaphragm Gages

A great deal of the prejudice against the diaphragm gage is blind or unfounded. One cause of it may be that an elastic-diaphragm gage can be manufactured inexpensively; whence it comes that the cheapest miniature gages on the market (excluding, of course, tire testers, etc., but including only dial gages) are diaphragm gages.

Cheapness indeed appears to be (at present) a big talking point of most gages utilizing only the elastic deformation of a metal diaphragm (without a separate calibrated spring). This seems to be true of both flat and corrugated diaphragm springs. Except for service below 10-lb gage, accuracy and permanence of calibration do not seem to constitute the talking point. The reasons are probably the following:

(1) In the case of a flat diaphragm: The actual deflection at the center of a diaphragm having a diameter about equal to that of the dial cannot be more than a very small fraction of the pointer travel over the scale. Otherwise the diaphragm spring would be stressed beyond the range of permanent accuracy. Thus the diaphragm must be *large* in relation to the dial of the instrument; and obviously it is impractical from a manufacturing standpoint to make it *larger*. Therefore a movement is required providing a large factor of multiplication—multiplying both the diaphragm motion and its deviation from true elastic behavior, not to mention mechanical errors.

(2) In the case of a corrugated diaphragm: A smaller diaphragm may of course be used but is so happens that of all primary elements used in industrial instruments, none is more "erratic" in its response to the measured force than a corrugated diaphragm. Meaning that the theory has not yet been worked out in a scientific way. Consequently, the corrugated diaphragm is often employed as a flexible or "slack" element in connection with a calibrated spring.

This having been set forth, it must now be said that the diaphragm gage serves a definite purpose in a definite field that cannot be served by the Bourdon spring gage:

For low-pressure service, below 10-lb per sq. in., a good diaphragm gage is more accurate and durable than a Bourdon spring gage. For measuring the pressures of chemicals which would quickly destroy a Bourdon spring, nothing has ever been found that is superior to the diaphragm gage: The diaphragm may be made of a material to withstand the corrosive action of the chemicals on which it is to be used, or the diaphragm may be protected

by a suitable foil. "Chemical Gages" (Schaeffer system) for service up to 300-lb gage are covered by the same guarantee (accurate to within 1% of scale range, etc.) as the Bourdon gages of the same make, in the latest catalog of the largest manufacturer of such instruments.

As to accuracy: Greater care is required in calibrating diaphragm gages than is required on Bourdon and other tube-spring gages. The movement of the diaphragm is not as uniform as that of a Bourdon or other tube-spring, but by hand calibration and hand marking of the dials proper accuracy is assured. This applies only to the high-grade gages.

Even among the cheaper grades, recent improvements and better inspection methods have placed on the market a number of excellent values in the way of small-size quantity-production diaphragm gages. It must be remembered that along with the demand for highly accurate pressure measurements on important applications, there is also an increasing number of industrial applications where accuracy of pressure measurement is not called for—applications where the major requirement is simply to know whether the pressure is on or off and the minor requirement to measure the pressure.

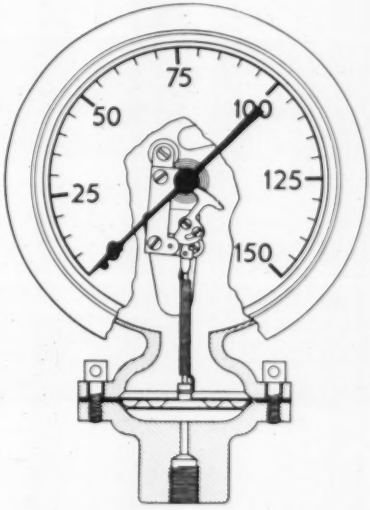


Fig. 308. (*Consolidated Ashcroft Hancock Co.*)

The best illustration of this is an air-operated automatic controller. The controlled air line gage can at best show a rough indication of the extent to which the diaphragm-motor valve is open. And to check this gage it is only necessary to open wide the air valve in the controller: if the reading of the controlled air line gage then corresponds to that of the air inlet gage, the former gage is correct. Both gages may be "off" but if they agree under the same pressure, they will do.

The disadvantages of the diaphragm gage—even if it be of the highest grade—are as follows: (1) The diaphragm cannot be subjected to as much overpressure as a Bourdon spring. (2) A slight overpressure may cause it to take a set. (3) The dial is hand calibrated so that it is practically impossible for the user to adjust the gage in the field. (As to the low-grade diaphragm gages it generally pays to chuck them away and buy new ones when they become too inaccurate).

Fig. 308 was made for this handbook in March 1931, and therefore shows the latest construction of a modern diaphragm gage (indicating, with hand-calibrated dial).

In examining a number of photographs sent in by gage manufacturers the author could not resist the temptation of juxtaposing two of them, in order to show the many fields of application (it is not deemed advisable to say "the extremes") of diaphragm gages. The little gage shown in Fig. 309 is shown full size; Fig. 310 is about one-fifth actual size. The former is an indicator, the latter a recorder. Other comparisons would be indiscreet,

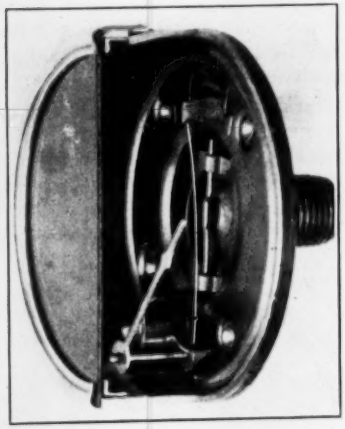


Fig. 309. Restrained-diaphragm gage designed to withstand overloads. (*Rochester Mfg. Co.*)

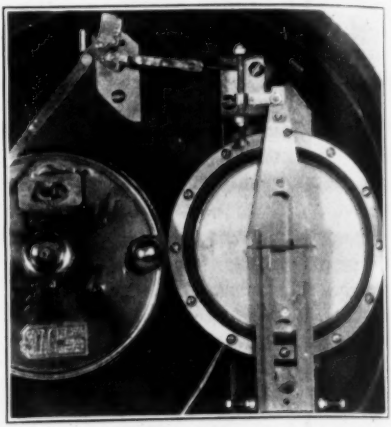


Fig. 310. Partial view of mechanism of recording diaphragm gage for low pressure (*C. J. Tagliabue Mfg. Co.*)

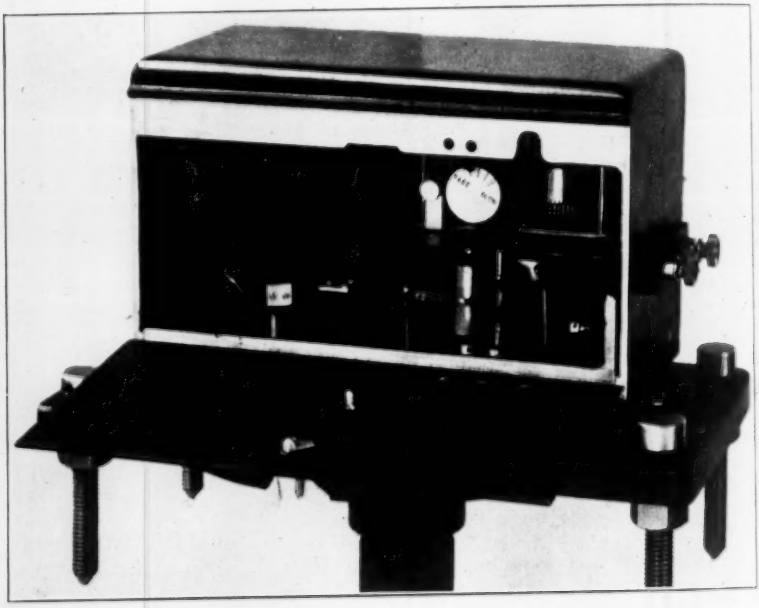


Fig. 311. Sensitive high-speed recording draft or low pressure gage. (*Cambridge Instrument Co.*)

Fig. 312. Portion of record obtained in locomotive exhaust blast test with gage shown in Fig. 311.

DIVERSE TYPES OF INDUSTRIAL DIAPHRAGM PRESSURE GAGES

but it is interesting to report that *seven million* of the former are in use, according to the maker. Of the latter, a *comparatively* insignificant number are in use—but mostly on important industrial applications requiring accurate records of low pressures, around 5 to 100 inches of water. According to our classification, the pressure recorder shown in Fig. 310 is not an elastic-diaphragm gage but a spring-loaded slack-leather gage, of the class dealt with in Section 12. However, the designation "diaphragm gages" is applied to instruments of this type. In the field of gas meters, similar elements (though volumetric and not piezometric in purpose) are universally called diaphragms.

To combine perfect sensitivity with absolute freedom from inertial effects, in a mechanical pressure *recording* instrument, is the goal toward which designers of engine indicators are striving along well-traveled roads. A different approach, aiming at the accurate recording of high-frequency variations of *low* pressures, is seen in an instrument combining a corrugated diaphragm with a "micro-indicator" type of recording mechanism. Fig. 310 shows (about one-sixth actual size) a form of this instrument designed particularly to record the draft in locomotive smokeboxes, where fluctuations may exceed 1000 per minute.

The suction produced at each exhaust beat, and the variations between beats, are recorded by the action of a spherical-point stylus on a celluloid film. A second stylus, actuated by an electro-magnetic timing mechanism, marks a time scale on the graph—generally tenths of a second—or it may be arranged to mark revolutions, in order to identify the exhaust blast beats, as in Fig. 311. This shows a portion of a typical record from a two-cylinder locomotive. The speed at which the film travels past the stylus may be adjusted between wide limits. The movement of the corrugated diaphragm is constrained by a stiff flat spring and the recording stylus is fixed at the end of this spring, so that there is no need of a pencil motion. With moving parts thus reduced to a negligible weight in comparison with the restraining force, the natural period of the mechanism is very high.

Mention may be made of the thin non-metallic unloaded elastic-diaphragm gages. These are scientific instruments, however, for the present at least, and need not be dealt with here.

(b) Bellows Gages

Much of what has been said above concerning diaphragm gages applies here and need not be repeated. The bellows is a time-tried pressure measuring element and is particularly suited for very low pressures. It is found in a variety of forms, at one extreme of which the element may be considered a series of diaphragms or of capsular springs connected at the center, and at the other extreme a corrugated tube or Sylphon.

Strip-chart recorder and round-chart recorder bellows movements, of three prominent industrial makes, are represented in the group of illustrations on page 154. Fig. 313 shows a bellows unit (for very low pressure, or draft, as is obvious from the diameter of the bellows) in a strip-chart recorder. A feature of this design is the division of the instrument case into two compartments, the front for the recorder mechanism, chart, etc., and the back compartment for the measuring unit proper. (This is the interesting standardized arrangement of all graphic instruments—mostly electrical—made by this firm.) Figs. 314 to 316 show bellows units which the maker embodies either in round-chart or in strip-chart recorders. Fig. 314 shows a bellows element applicable to pressures from 4 inches to 12 inches water. It consists of a series of "hollow metal discs" or capsular springs, connected in the center and strapped together on one side. The

BELLOWS OR SERIES OF DIAPHRAGMS AS EMPLOYED IN PRESSURE RECORDERS

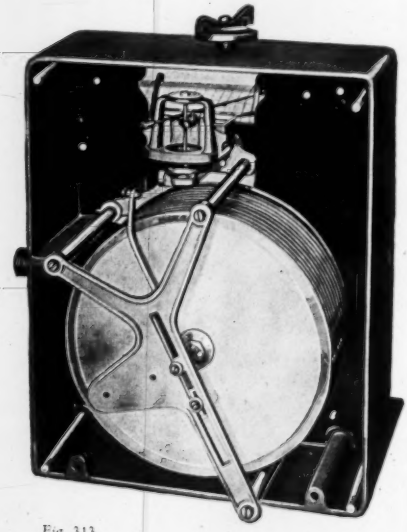


Fig. 313
Esterline-Angus Co.

Fig. 316
The Bristol Co.

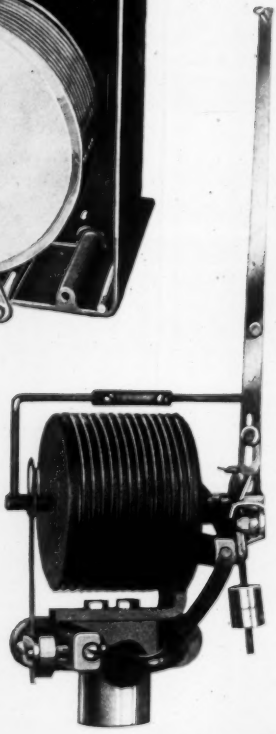


Fig. 315
The Bristol Co.

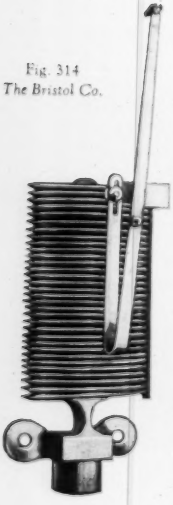
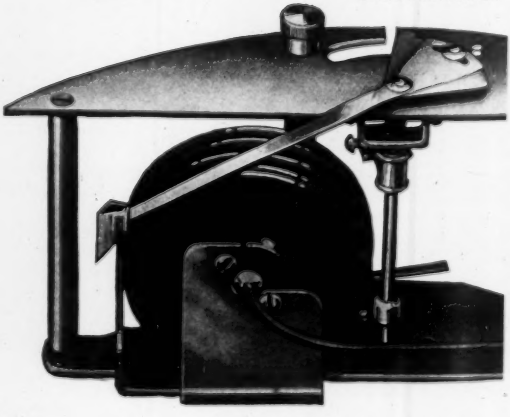


Fig. 314
The Bristol Co.

Fig. 317
Brown Instrument Co.



strap permits side movement only in one direction. This unit is designed for mounting in the position shown and is not intended for use in an inverted pen-arm recorder. Fig. 315 is known as the "knife-edge type" and is characterized by the combination of ruggedness and freedom of movement. It, too, is designed for mounting in the position shown. Unlike that shown in Fig. 314, however, it can be used for measuring either vacuum or low gage pressure.

The "box type" unit, Fig. 316, can be mounted in any position in any desired style of recorder. It measures pressures up to 10-lb gage, but is not designed for draft or vacuum applications. It consists of a short bellows enclosed in a pressure-tight box. Pressure is admitted to the inside of the box and *outside* of the bellows which operates the pen-arm by means of a shaft. The movement of the pen-arm is "very positive and records clearly even rapid fluctuations . . . The characteristic of this movement is dead beat."

A series of pairs of stamped phosphor bronze corrugated diaphragms makes up the bellows element in the mechanism shown in Fig. 317 (whence the maker's designation "diaphragm gage" for what is plainly a bellows gage to our way of thinking). It is designed for pressures below 30-lb gage or for draft or vacuum measurement. An interesting feature is that the bellows is mounted on a segment which can be turned by the knob visible in the illustration, permitting easy and precise zeroing.

12. Spring-loaded Membrane Forms

This Section is descriptive. For principal characteristics see Tables IX, XVII, XVIII and XIX. For specifications, tests, adjustments, etc. see Section 15. For calibration methods see Section 2. For industrial accessories, features, etc. see Section 16. For properties of elastic members *alone*, see Section 9. For classification of errors of an elastic-member instrument *as a whole* see Section 13, heading (e).

According to the scientific classification of pressure-measuring elements, the gages now considered belong with the diaphragm gages dealt with in the preceding section. Practically, however, and especially with due regard to industrial uses, it is well to segregate them. Diaphragm gages are regularly made up for pressures up to 300-lb gage and sometimes higher; while the instruments here dealt with are mostly draft gages and are only made up for low pressures—seldom greater than 50 inches of water (not quite 2-lb gage) and never regularly above 100-in. or 4-lb gage.

The principle is that of the *slack* diaphragm absorbing no energy theoretically (actually absorbing a negligible amount) and merely transmitting the force of the draft or pressure to the elastic-member which measures this force by its deflection. This permits the use of an elastic-member of any desirable form and of any material possessing the required combination of static and dynamic physical properties. Phosphor bronze cantilever springs are well suitable for the purpose and are employed in the majority of slack-membrane gages. Research on cantilever springs has proceeded quite far, and so have investigations of phosphor bronze, so that the design of this comparatively new class is actually on a surer footing than is the design of any other elastic-member class.

As the illustrations show, this class of gage is made up into instruments which on the outside resemble closely some of the inverted bell draft and low-pressure gages described in Section 8. Naturally there exists a lively and healthy competition. Naturally, too, some engineers may remark that the inverted-bell class, being gravitational, is primary, whereas the spring-loaded membrane is a secondary pressure-measuring element. In addition, some engineers might also call attention to the fact that this very Handbook seems to favor inverted-bell draft gages against the spring-loaded membrane gages because of the accuracy figures

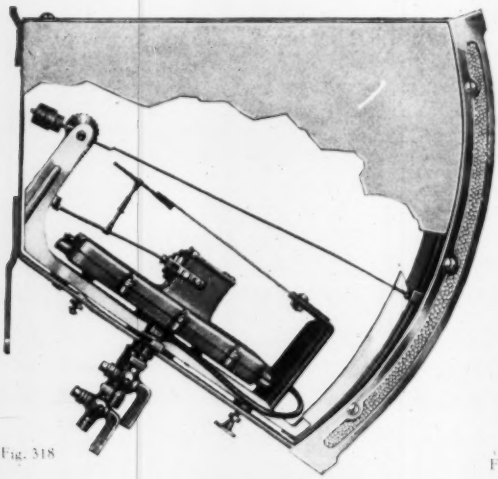


Fig. 318

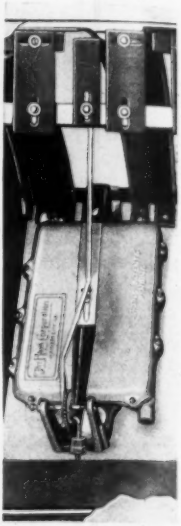


Fig. 321

SPRING-LOADED SLACK-MEMBRANE INDICATORS FOR LOW PRESSURES OR DRAFT

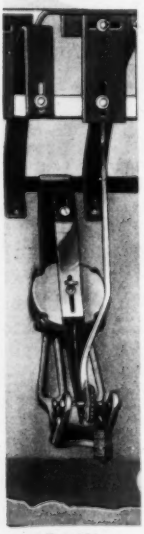


Fig. 320

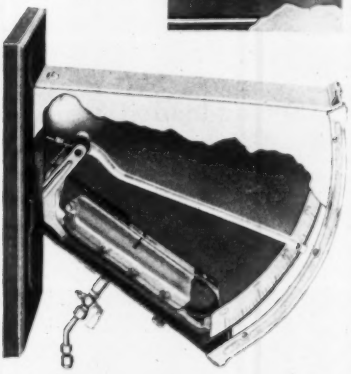
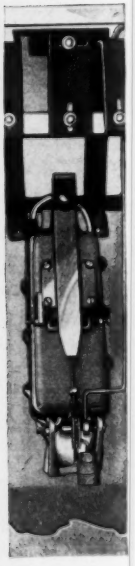


Fig. 322

Fig. 319



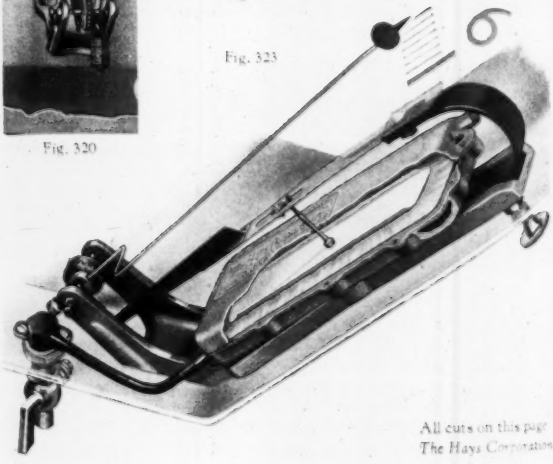


Fig. 323

All cuts on this page The Hays Corporation

which appear in Table XVII. It is not amiss, therefore, to mention right here that the figures in Table XVII were supplied by the Chief Engineer of the largest makers of spring-loaded membrane gages. He handsomely "leaned over backward." It is well to mention (for perhaps the twentieth time in this book) the fact that features of design and construction of particular instruments can have a very decided effect, and to add that the amount of force available, compared with the inertia to be overcome and work to be done, is something worth considering. Theoretically, a primary instrument cannot err; actually, one may discern what we call "bugs." For example, some inverted bells of comparatively small area operate against a fairly heavy mechanism having six bearings or points of wear, so that only excellence of construction can produce anything approaching theoretical performance. The discussion may be closed with the following extract from a letter to the author from the president of that same company: "... We use a large diaphragm area to bend a spring well within its elastic limit and the pointer is of the lightest possible rugged construction ... a single pivot bearing ... While we have never claimed that our spring-loaded membrane had as fine an ultimate accuracy characteristic as the real large inverted bells or large float types, we have felt that we were combining in a simple way ... other desirable practical features such as the self-sealing of the diaphragm under excessive pressures without harm to the mechanism, a simple zero adjustment and an entire absence of liquids, floats, tanks, gears, cams etc. ..."

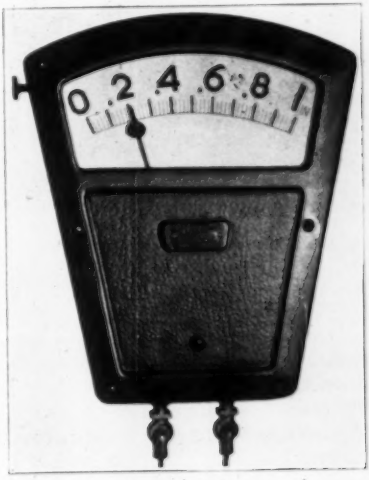


Fig. 324

Four types of spring-loaded membrane mechanisms are shown on page 156. For the most sensitive ranges of draft or pressure below ½-in. water, the "super-sensitive" mechanism shown in Fig. 321 is employed. For ranges of draft or pressure within scale ranges 0 to 0.6-in. water and 0 to 10-in. water, the "standard" mechanism shown in Figs. 322 and 323 is employed. For pressure or draft ranges above 10 inches water total scale (but not exceeding 100-in.) the "medium range" mechanism shown in Fig. 320 is employed. Note that a small round membrane is used, giving a smaller diaphragm area. For the measurement of differentials not exceeding 50 inches water, the "standard differential" mechanism illustrated in Figs. 318 and 319 is employed.

These units are embodied either in fan-shaped or in "edgewise" cases. The latter are made up in multiple units up to any desired width, but note that the wide "super-sensitive" mechanism occupies two spaces in the multi-pointer arrangements.

The fan-shaped cases can accommodate one or two units, the two-pointer gage having one mechanism on each side. See Fig. 323.

A new type of case, announced in March, 1931, is shown in Fig. 324. It is 9½ in. wide—exactly half the width of the fan-shaped case. This case is large enough to accommodate two units. An interesting feature of this gage is that the cast iron or cast aluminum case can be made absolutely air-tight so that by admitting one pressure merely into the interior of the case, a differential reading is obtained with the standard mechanism. The gage shown in Fig. 324 is of this differential type.

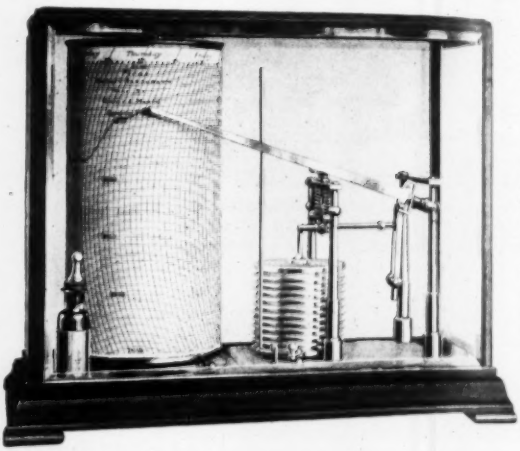


Fig. 325. (Taylor Instrument Companies)

13. Aneroid Barometers and Capsular Spring Gages

This Section is descriptive. For principal characteristics see Tables IX, XVII, XVIII and XIX. For specifications, tests, adjustments, etc. see Section 15. For calibration methods see Section 2. For industrial accessories, features, etc. see Section 16. For properties of elastic members *alone*, see Section 9.

Human lives depend on the indications of aviation instruments; great amounts of labor and money on those of surveying aneroids. Hence the intense thought devoted to their improvement (especially since the war) by manufacturers, societies and governmental departments. The class of instruments now considered includes the finest examples of the art of making commercial instruments and sets a high standard which results in constant parallel improvements in the purely industrial instruments of some other classes within the elastic-member group. Official and semi-official studies have resulted in extremely enlightening reports.

(a) Classifications

In this class of pressure instruments there are two sub-classes: (1) the instruments depending on the deflection of a capsular spring, double-diaphragm, etc., without external spring; and (2) those embodying a flexible box or capsule, whose motion is restrained by a separate carefully calibrated spring. These latter constitute the majority and as a rule perform better.

Another division of this class is into (1) instruments embodying an *evacuated* thin-walled vessel; (2) those in which the measured pressure is applied *inside* the capsule; and (3) those of similar general design but capable of measuring *differentials* across flow meter primary elements, so that atmospheric pressure acts neither inside the capsule nor directly on its exterior.

(b) Industrial Barometers

The well-known "Engine Room" barometer was shown in Fig. 217. It is designed especially for gage board mounting, is graduated from 25 to 31 inches of mercury in fiftieths of an inch and is compensated for temperature. Fig. 325 shows the "Micro-Barograph" which combines an exceptionally sensitive movement with a high (*i.e.*, wide) chart the scale of which covers 6½ inches for a range from 28.50 to 31.00 inches of mercury.

An Exception is Put on Record—Throughout this Handbook there are references to the National Bureau of Standards and to the American Society of Mechanical Engineers, the frequent occurrence of which suggests—and correctly—a leaning toward these two authori-

ties. In connection with aneroid barometers it appears that statements made in the already published sections of the A.S.M.E. Power Test Codes do not meet with universal acceptance; and fairness compels giving here extracts from a communication to the author from E. J. C. Purton, Meteorological Division, Taylor Instrument Companies:

"With regard to the statement in the A.S.M.E. Power Test Code, Part 2, Chapter 1, that the average barograph 'is open to suspicion,' we would state that the result of the research work . . . has enabled us to embody certain changes . . . to a point where we believe good barographs will hold their calibration and once the calibration errors are determined, they would not need frequent attention.

"The remark contained in paragraph 16 that 'at best the temperature correction is uncertain.' This correction cannot be found in tables as can the correction for mercurical barometers. It must be determined by actual test, but when once made, it cannot be said to be 'uncertain' for under the same conditions of temperature and pressure the same correction must be applied.

"According to our own findings the statements made in Parts I and II . . . are considerably exaggerated. For instance, the curves shown in figures 1 and 2 for maximum hysteresis show about 50% and figure 3 about 40%, whereas instruments as a general rule do not have hysteresis over 2% of the pointer movement and good instruments invariably are considerably less than 1%."

(c) Standard Capsular Element Instruments

By "standard" we differentiate the instruments now to be described from the "null method" instrument described under the next heading.

Fig. 326 shows an aneroid box instrument with restraining spring—that is to say a barometer, but the particular construction shown is that of an approved type of altimeter. As was mentioned in Section 9, not only are altimeters refined barometers but they represent the greatest progress made in elastic-member instruments in recent years. The capsule or aneroid box C is evacuated and sealed. Normal air pressure will tend to keep it contracted with tension on the spring S. As the aircraft climbs, the atmospheric pressure on the capsule decreases, allowing the spring to expand it. Attached to the spring is the long lever L which connects with multiplying links and

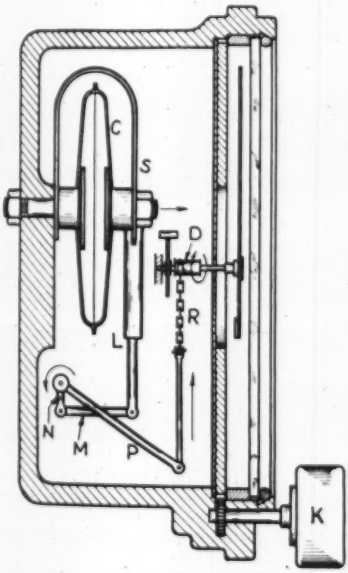


Fig. 326 (Pioneer Instrument Company)

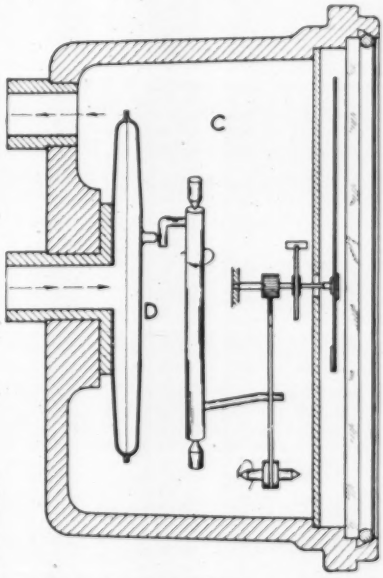


Fig. 327

levers M, N and P as shown, ending with the fine chain R which wraps around the drum D on the pointer spindle. A small hair-spring keeps the mechanism taut. Pure nickel chain and jeweled bearings serve to eliminate friction in the mechanism. The instrument is shown nearly full size.

Fig. 327 happens to be the sectional drawing of an aviation instrument, but with slight modifications such an instrument should find many industrial plant applications. As may be seen at a glance it is designed for the measurement of pressure differentials. On aircraft it is connected to a pitot-static or other primary element located in the slip-stream, thus permitting the air speed of the craft to be indicated at the instrument. In other words, this type of air speed indicator is a sensitive differential pressure gage. The higher or total pressure is admitted to the inside of the capsular spring, and the lower or static pressure to the inside of the case which is air-tight. This same principle has recently been employed in a purely industrial differential gage (Fig. 324).

(d) Null Method Aneroid Instrument

The advantages of the null method have been pointed out in earlier chapters. Briefly, it consists in utilizing the deflection of an indicating element to indicate only a state of unbalance between the measured force and an exactly-known opposed force, just as does the pointer of a weighing balance. The only elastic-member pressure-measuring instrument successfully utilizing this method at the present time is the barometer or altimeter shown in Figs. 328 and 329. This instrument was announced as "A New Pressure Gaging Instrument" in *Instruments*, August, 1928, page 381. It is not amiss to insert here a technical description (by R. D. Kelly in the *Aeronautical World*):

By reason of friction, elastic hysteresis and drift (or lag), the use of the aneroid for purposes where accuracy was required has been almost impossible. Every joint (chain included) and bearing is a source of friction. Elastic hysteresis and drift result from inelastic qualities of metals which are under stress and which move. The chief source of these has been the evacuated box which expands and contracts with variations in atmospheric pressure and which is constructed of materials which are not perfectly elastic. If we add to these other errors which are due to temperature, construction, balance and the like, it is evident that a marked improvement is necessary if really accurate results are to be achieved.

During the long period that has elapsed since the present construction of aneroids was brought about, only minor successes have been achieved in effecting rather insignificant improvements. Such obstacles to the instrument's accuracy as frictional resistance have appeared unavoidable. There were, moreover, the aforesaid errors due to changes in temperature and the elastic hysteresis.

The Swedish engineer, G. Paulin, of Stockholm, has by means of an ingenious idea solved the problem in such a way that: (1) All bearings between the evacuated box and the pointer are eliminated. (2) The evacuated box, by the use of the zero-gaging method, is always brought into an exactly normal position when reading the instrument. (3) Stops are provided which limit the expansion and contraction of the evacuated box to an insignificant amount.

Fig. 329 is a diagrammatic sketch of one of the earlier Paulin System instruments. The instruments have since been considerably improved . . . The principle remains the same, however, and the explanation of it is made from a cut of the earlier instrument rather than from one of the later more compact and improved models.

The system consists of one or more evacuated metallic boxes *A* which are mounted on a base and connected to a rather sturdy spring *C* by means of a lug B. The expansion and contraction of the metallic boxes is limited to approximately 0.001 inch. This is accomplished by means of a bar extending between the two upright supports and the two set screws in lug *B*. Only the upper set screw is visible in the drawing, the other one operating in a similar manner beneath the bar. The restriction of the movement of the mateallic boxes is an important improvement since thereby the hysteresis and drift of the instrument are considerably reduced. The upper end of the spring is secured to a threaded lug *D*. Operating in this lug is a micrometer-screw *E* by means of which the tension in the spring can be increased or de-

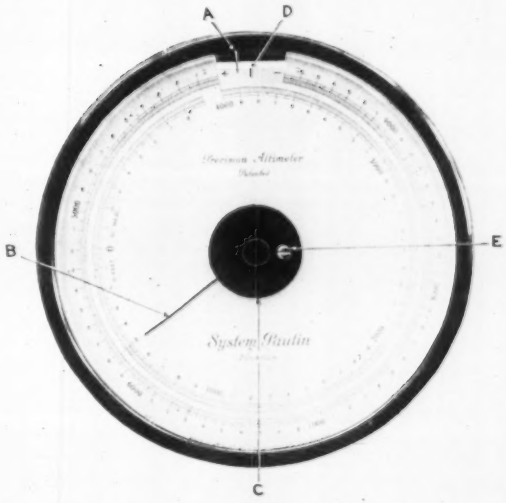


Fig. 328. Altimeter employing null method of measurement of atmospheric pressure.

A—Balance Indicator.
B—Pointer.
C—Setting Knob.
D—Balance Mark.
E—Pointer Adjusting Knob and Screw.
(American Paulin System, Inc.)

creased. The arm extending to one of the upright supports prevents lug *D* from turning when screw *E* is rotated. *E* is operated manually with the "setting" of the instrument, and the large pointer *O* is integral with it.

In order to determine the atmospheric pressure, the screw *E* is rotated by means of button *G* until the tension in the spring exactly counterbalances the atmospheric pressure upon the evacuated metallic boxes *A*. When this condition exists, the suspension of the boxes *A* and spring *C* will be perfectly free, neither of the set screws being in contact with the bar, and the angular location of the pointer *O* on the dial can then be taken as a measure of the atmospheric pressure.

In order to determine exactly when the above condition of balance is obtained it was necessary to devise a very sensitive frictionless means of indication. This problem was solved by Mr. Paulin . . . A cradle *K* is attached to the lug *B*. It therefore moves up or down with any expansion or contraction of the metallic box (within the 0.001 inch limit between the set screws). At each end of the cradle is attached a phosphor bronze strip *J* which is secured at its other end to the base. To the center of each of these strips is attached another phosphor bronze strip *H*, the opposite end of which is secured to a short lever arm extending through a shaft *L*. Shaft *L* is suspended between two springs *M* (eliminating the necessity of a bearing), and carries a long shaft *I*, one end of which is known as the Tendency Pointer. The other end *N* (counterbalance) terminates in an oil dashpot *P* which serves to steady the indication of the Tendency Pointer. Careful analysis of this scheme will reveal that a very small movement of the cradle *K* will result in a relatively large movement of the Tendency Pointer without the incurring of any bearing friction whatsoever.

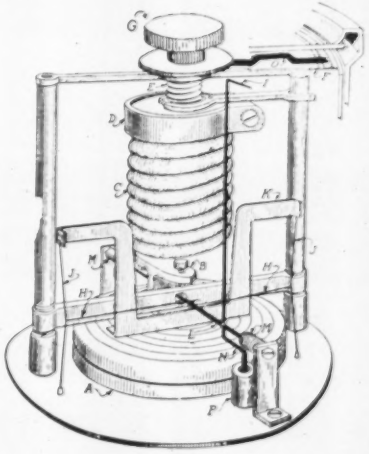


Fig. 329

The instrument is so adjusted that when the Tendency Pointer (which extends through the dial) is at the middle or zero position of its travel, an exact balance is obtained between the spring and the atmospheric pressure upon the evacuated metallic boxes. Thus to read the instrument it is only necessary to rotate the screw *E* by means of the setting knob *G* in the direction to bring the tendency

pointer to its zero position. Reading the position of the pointer *O* on the scale *F* then gives the air pressure in the desired units. The stops prevent injury to the zero indicating system when the tension of the spring does not balance the atmospheric pressure upon the metallic boxes, and the instrument cannot be harmed by being taken to altitudes beyond that of its range. The sensitivity is only limited by the possibilities of reading. With special Paulin System instruments differences in elevation have been measured that were no greater than the length of an ordinary matchbox.

Other advantages are: (1) The instrument-scale can be made much more clear and distinct than on ordinary aneroids. (2) The elastic hysteresis and drift (or lag), even in the case of great or rapid changes in altitude or elevation, has been reduced to practically nothing. (3) . . . The "temperature coefficient" is remarkabley low and it has . . . proved to be about ten times more constant for normal changes in temperature than with ordinary aneroids.

The successful employment of the null method in one elastic-member pressure instrument shows that it could be employed in others. Instead, however, of jumping to conclusions, of making rash predictions and of imputing that manufacturers of industrial pressure instruments are asleep, the author deems it prudent to record an authoritative expression that has all the earmarks of an objection against null method altimeters. Says F. H. Peters, Surveyor General of Canada:

It passing it may be said that an aneroid, to stand up under field conditions, must be extremely robust, considered as an instrument. It must not change its indications by more than 10 feet or so under what might be thought quite severe blows. This consideration rules out many ingenious, but frail, instruments which have been devised to replace the usual form of aneroid. So far, in the large number of instruments tested by the Physical Testing Laboratory, none has yet been found which is more accurate than properly designed and constructed aneroids of the direct reading type.

(e) Classification of Errors

In the regretable absence of an authoritative organized research on the errors of elastic-member pressure instruments, something almost equivalent is afforded by the data contained in the well-known Bureau of Standards Circular No. 46, "Testing of Barometers and Altimeters" issued in 1922. So admirably complete was—and is—this circular that a marked copy recently received by the author from the Assistant Director of Research of the Bureau contains only four major corrections. The following extract on errors of aneroid barometers is therefore up-to-date, beside being interestingly suggestive with reference to all other classes of elastic-member pressure instruments (the italics are ours):

The errors of an aneroid barometer depend to a considerable extent upon the conditions under which the instrument is being used and may, indeed, undergo secular changes. It is, however, by no means true that the aneroid barometer is entirely erratic and undependable, for while the errors of these instruments are numerous, large, and variable, their magnitude can be approximately determined in each case. The variation of any given error, though perplexing to a person obliged to use the instrument, appears to follow definite physical laws. While, then, it is true that corrections for the errors of an aneroid barometer can not be so satisfactorily made as can those of a mercurical barometer* they can nevertheless be determined to a practical degree of accuracy depending on the time and care, which is devoted to testing and correcting the instrument, providing, of course, that the aneroid is initially free from mechanical defects.

The errors of aneroid barometers may be classified as (1) *transient*, (2) *secular*, and (3) *inherent*.

1. *Transient* errors are those due to the aneroid not being in a physically steady state. They can be avoided by waiting long enough before reading.

2. *Secular* errors are those due to changes taking place over a long period of time. While true secular errors may exist owing to the gradual settling of the parts, as was found in certain instruments constructed hurriedly during the war, these need not be of serious concern if the instrument is checked up from time to time with a standard mercurical barometer. Beside the true secular changes there are rather sudden changes which would on first thought be supposed to be secular changes but which are either shown by close observation to be sut-

*No longer true in the case of good instruments, unless you want to investigate *all* errors, including those that can scarcely be detected at all.—M. F. B.

ficiently explicable in terms of elastic lag resulting from the daily fluctuations of atmospheric pressure, or which may be ascribed to some actual injury of the instrument.

3. The *inherent errors* are those due to imperfections of design or construction and to the physical properties of the materials used in construction. These may be subdivided under three heads, namely, (*a*) *mechanical* errors, (*b*) *thermal* errors, and (*c*) *elastic* errors.

(*a*) The chief *mechanical errors* are those due to the necessity for a compromise between friction and back'ash in the linkwork and those due to the difficulty of securing perfect balance among the movable parts. To minimize the effect of mechanical errors, (1) always read the aneroid in the position in which it was tested, and (2) tap the instrument sharply just before reading.

(*b*) *Thermal errors* are due to the expansion of the parts and to change of the stiffness of the elastic members of the aneroid (the spring and aneroid capsule) with varying temperature. to correct for these errors, the instrument should be tested under as great a range of temperature as will be encountered in practice. Aneroids which are marked "compensated" are only compensated for the effect of changes of temperature on the readings at sea-level pressures and do not take into consideration the effect of change of stiffness of the elastic system on the readings at low pressures. Some aneroids which are well compensated at sea level for ordinary temperatures show very inadequate compensation at extreme temperatures. Instruments can be purchased, however, which are successfully compensated over a range of 100° F.

(*c*) *Elastic errors* are caused by the imperfect elasticity of the metal of the aneroid capsules and springs. These errors are usually designated by the single term "elastic lag" and may be classified under the three following designations: (1) Drift, which is the increase of reading, when the instrument is held at a constant low pressure for several hours; (2) hysteresis, which is the excess of the reading with increasing pressure over that with decreasing pressure for a given pressure and which is also evidenced by the fact that the reading at any given pressure depends on the previous rate of change of pressure; and (3) after-effect, which is the amount by which the pointer fails to come back to the initial reading after any complete cycle of pressure changes; for example, the failure of the pointer to return to its initial reading when the instrument is brought back to the original ground pressure.

The existence of the first of these effects necessarily leads to that of the other two. Whether there exists a type of hysteresis due to reversal of action independently of time or not * (recent experiments on springs at the Bureau of Standards seem to point to this type of hysteresis), it is probable that the predominating errors are those due to drift. The most important precaution to take in order to avoid the effect of elastic errors is to ascertain in advance, and most conveniently by the regular bureau test, the drift which takes place in, say, five hours. In fact, it is possible to correct, roughly, for the effect of elastic errors when the exact circumstances under which the instrument was employed are known, particularly the rate of change of pressure.

An extensive investigation of aneroids has recently† been carried out by the Bureau of Standards, the results of which have made it possible to construct aneroid barometers in which all the *common errors of ordinary instruments* have been practically eliminated. Some of the *defects encountered in ordinary instruments* are as follows:

(*a*) Irregular graduation of the scales.

(*b*) Altitude scales which can be rotated relative to the pressure scale when the altitude scale is not divided into equal parts.

(*c*) The barometer fitted with a mechanism properly belonging to a smaller size case.

(*d*) The substitution of flexible fiber in the multiplying system for the usual metallic strip or chain.

(*e*) The adjusting screw in the base having so large a pitch that in attempting to adjust the position of the pointer the smallest possible movement of the screw driver moves the pointer over a large part of scale. Attention should be called here to the use of this adjustment, since if the pointer has moved more than a tenth of an inch it should be reset on the arbor and the finer adjustment made with the adjusting screw.

(*f*) Instruments engraved with the word "compensated" and yet not provided with any temperature-compensation device.

(*g*) Instruments having large errors of parallax due to the pointer being set a relatively large distance from the dial. This is true of instruments employing a sprial groove on the pointer arbor as a multiplying medium.

(*h*) Excessive vibrations of the pointer in aircraft instruments.

(*i*) Changes in the character of calibration curve in certain instruments constructed during the war, when the elastic elements of the instrument were not given a chance to age properly.

*There does exist this kind of hysteresis in *all* elastic materials. Recent research has shown that the ideal elastic material does not exist.—M. F. B.

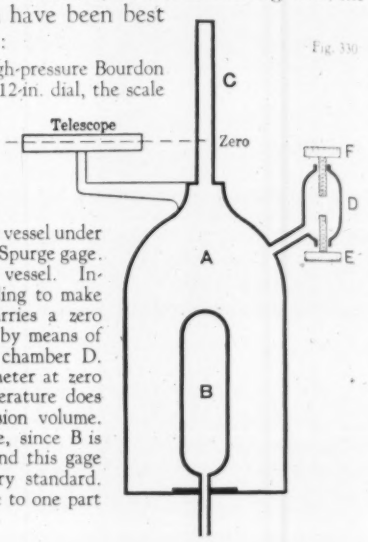
†This publication of the Bureau is dated December 26, 1922.

14. Other Elastic-member Forms

There do not remain any industrial elastic-member instruments. All of those on the market fall within the classes covered in Sections 10 to 13. A number of scientific laboratory instruments also fall in these classes, all but one—the Spurge gage, an English invention, illustrated in Fig. 330, the advantages and description of which have been best summarized by Diederichs & Andrae:

Fig. 330

A further difficulty encountered with the high-pressure Bourdon gage is the closeness of the scale. Even in a 12-in. dial, the scale would not exceed 30 in. in length, and in a 6000-lb. gage this would mean that each inch stands for 200 lb. Reading to say 0.05 in., would still make each scale division = 10 lb. It is sometimes desirable to read high pressures closer than this. This can be done by measuring the volume expansion of a tube or vessel under internal pressure, which is the principle of the Spurge gage. A is a vessel holding water, B, the elastic vessel. Internal pressure in B causes expansion, tending to make the water rise in the tube C. The latter carries a zero mark at which the water level is maintained by means of adjusting the micrometer E in the expansion chamber D. F is an adjusting screw used to set the micrometer at zero for zero pressure. If, during a test, the temperature does not change, E measures accurately the expansion volume. This is not a linear function of the pressure, since B is subject to both radial and axial expansion, and this gage must therefore be calibrated against a primary standard. It is claimed that this instrument is accurate to one part in 2000.



15. Specifying, Testing and Adjusting Elastic-member Gages

This section gives miscellaneous useful data for engineers and for practical users. No attempt has been made to compile specifications, tests and methods of adjustment for *all* classes of gages. Instead, one class only is referred to under each heading. The selection has however been made with a view to general interest in spite of the fact that the quotations refer specifically each to one rather limited group of instruments.

(a) U. S. Navy Specifications for Indicating Pressure and Vacuum Gages for Air, Steam, Oil and Water.

As this heading implies, these specifications cover the gages of types which are most universally used in all industries. "Bourdon tubes" are specified for all gages except oil gages and air gages reading to 50 lb or under, where no mention is made of the elastic member; but the context *implies* (we believe) that even for this type the navy requires Bourdon tubes. To print these specifications in full (in the smaller size of body type used in this book) would require eight pages. They include five illustrations of dials which need not be reproduced because in each case one of the figures on page 144 shows the requirements close enough for most purposes. So much has been said in favor of these Navy specifications, and so little against them, that the extracts below may be recommended as models for industrial specifications:

MATERIAL AND WORKMANSHIP.

3. (a) All material entering into the construction of gages shall be free from all defects and blemishes that in any way affect the appearance or serviceability of the gages.

(b) Workmanship shall be first class in every respect.

GENERAL REQUIREMENTS.

4. (a) *Cases*—All gages except type D shall be furnished with heavy red brass, polished, and lacquered cases, threaded to take the screw bezels. The first two threads shall be turned down to the diameter of the bottom of the threads The composition shall consist of at least 80 per cent copper with a suitable mixture of tin and zinc. The gages shall be provided at the back with a flange drilled with three holes uniformly spaced for securing the gage to the board. All cases shall be of shallow type unless otherwise specified.

(d) *Fittings*—All gages shall be fitted with black lacquered indicating hands, and a red lacquered fixed hand, which can be riveted in place to show working pressure. All gages except pressure gages over 750 pounds shall be fitted with a suitable heavy gage cock, which shall be tested with the gage.

(e) *Dials*—(1) . . . All gages shall be accurately and correctly graduated up to and including the last division of the scale . . . The graduations shall cover an arc not less than 270°. Dials larger than 4½ inches shall be secured to the gages by three screws, dials 4½ inches diameter and under shall be secured by two screws . . . (3) If so required, there shall be placed on the dial between the manufacturer's marking and the hand pinion a silvered blank name plate, which shall be marked to indicate the purpose of the gage . . .

DETAIL REQUIREMENTS.

5. (a) *Pressure gages (750 pounds and under) type A*—These gages shall conform to the following requirements:

(1) Gages graduated to 100 pounds and under shall be fitted with a seamless Bourdon single tube; those graduated to more than 100 pounds shall be fitted with seamless Bourdon double tubes. Tubes fitted with auxiliary spring or stop will not be acceptable.

(2) . . . All wearing surfaces shall be of a suitable combination of metals to assure minimum friction or wear.

(3) Arbor bearings shall be deep bushed or otherwise fitted to give a bearing at least 1½ diameters long. The sector shall be of suitable hard, nonferrous material, with milled teeth, the face to be not less than 0.10 inch. Connecting links or plates shall be of suitable material not less than 0.05 inch thick. All moving parts shall be as light as possible consistent with the requirements of these specifications.

(4) Gages, type A, shall be furnished in accordance with the following sketch [omitted—style similar to pressure scale on dial of Fig. 295] and table of dimensions:

Diameter of dial.	Depth of gage (maximum).	Height of figures.	Briggs standard male pipe thread connection.	Pressure scale.				
Inches	Inches	Inch.	Inch.	Pounds	Pounds	Pounds	Pounds	Pounds
4½	2¼	9/32	¼	100	200	300	400	500
6	2⅝	⅜	¼	100	200	300	400	
8½	2¾	½	¼	100	200	300	400	
GRADUATIONS ON DIALS								
Pressure scale (pounds)				100	200	300	400	500
Scale divisions (pounds)				1	2	5	5	5

Gages over 500 pounds, up to and including 750 pounds, shall be engraved in 10-pound divisions.

(b) *Pressure gages (over 750 pounds), type B* . . .

(1) . . . seamless Bourdon single tube, made of high-grade spring or tool steel.

(2) The Bourdon tube shall be threaded and securely screwed into the stem of the gage. Solder may be used for the purpose of insuring the tightness of joints. In case of the use of solder the construction shall be such that no leakage will occur in event of softening of the solder when the gage is subjected to its maximum working pressure at a temperature not in excess of 145°F. Solder shall not be used for any other purpose.

(3) Gages in other respects shall conform to the requirements for pressure gages, type (A), except that they shall be furnished in accordance with the following sketch and table of dimensions: [omitted].

(c) *Vacuum gages and compound gages, type C* . . .

(1) . . . single, seamless, Bourdon tubes.

(2) The movement of the vacuum gages shall contain sector and connecting links as light as possible, consistent with good construction, durability, and strength . . .

(3) . . . [sketch of vacuum gage dial similar to dial of Fig. 293; of compound gage, to Fig 288].

(d) *Ammonia gages, type D* . . .

(1) . . . of approved pattern with seamless Bourdon single tube. Tubes shall be of high grade spring or tool steel. Sockets shall be of steel. Sockets and tubes shall be enameled or lacquered.

(2) Movement and other interior parts shall be of monel metal or of other nonferrous material nickel plated, or of suitable steel.

(3) Cases shall be of iron, black enameled, with brass nickel plated bezels. Cases shall be flanged as required in paragraph 4 (*a*).

(4) Gages in all other respects shall conform to the requirements for compound gages, type C, except that the dials shall have 30-inch vacuum, and 300-pound pressure scales. The vacuum scale shall have 5-inch divisions and the pressure scale 5-pound divisions. These gages shall be furnished in 4½ inch dial size.

(*e*) *Oil and air gages (50 pounds and under) type E* . . .

(1) Oil gages and air gages reading to 50 pounds shall conform to the special requirements for pressure gages under 750 pounds. The movement shall contain sector and connecting links as light as practicable, consistent with good construction, durability, and strength . . .

TESTS.

6. (*a*) One gage out of each 10 or fraction thereof of gages of the same type and scale reading shall be subjected to an endurance test as follows: A pressure equal to the maximum scale reading shall be applied for 1 hour. Within 10 minutes after the release of this pressure, and without recalibration or adjustment, the gages shall be subjected to the calibration test specified under (*b*) below. If the selected gage fails it will be rejected and two additional gages may be selected for test. If either fails the lot stands rejected.

(*b*) Calibration tests reading both up and down shall be made on each gage.

(1) *Pressure gages*—The error in reading at any point above 5 per cent of the maximum reading to which the scale is graduated, shall not exceed 1½ per cent of the maximum reading to which the scale is graduated; except that the error in reading at the graduation indicating the working pressure shall not exceed ½ per cent of the maximum reading to which the scale is graduated.

(2) *Vacuum gages*—The error in reading shall not exceed ¼ inch vacuum between 5-inch and 30-inch.

(3) *Compound gages*—The error in reading at any point on the pressure scale shall not exceed 1½ per cent of the maximum reading to which the scale is graduated. The error in reading on the vacuum scale of the 30-inch to 30-pound gage between 5-inch and 30-inch vacuum shall not exceed ½ inch of vacuum. The error in reading on the vacuum scale of the 30-inch to 100-pound gage between 5-inch and 30-inch vacuum shall not exceed 1½ inches of vacuum.

(*c*) Gages selected for tests shall withstand a temperature of 145°F. without showing any defects.

(b) Canadian Test for Aneroid Instruments

A recent paper by F. H. Peters, Surveyor General and Director of the Typographical Survey of the Dominion of Canada, gives what is probably the meatiest discussion of aneroid instruments ever put in 4,000 words; and ends with the new official acceptance specifications for portable temperature-compensated aneroid barometers scaled for 31 to 27 inches of mercury (0 to 4,000 feet). These specifications, though interesting, are rather too lengthy for our purpose. The acceptance test with which they conclude deserves however to be quoted here, almost in full, as of interest in connection with *all* elastic-member gages. Compare this test with the U. S. Navy's acceptance test for a totally different class of elastic-member gages.

Part 1. Preliminary Examination—The instrument is given a general examination to check the design, workmanship and existence of any obvious defects, or failure to comply with the "General" and "Mechanism" requirements. It is then subjected to the following tests to detect friction, looseness, lack of rigidity and want of balance:

(1) The instrument is tapped and the maximum range within which the hand comes to rest is recorded as the deviation by tapping.

(2) The instrument is held in the horizontal position and struck with some force against the palms of the observer's hands, first against the one hand and then (without rotating it) against the other. In each case a reading is taken immediately afterwards in the horizontal position. During several repetitions of this test, the greatest difference between any two (not necessarily consecutive) readings is recorded as the shift.

(3) The instrument is read in the horizontal position, after tapping gently, and immediately afterwards in the vertical position. The variation in reading gives the vertical correction.

Part 2. Temperature Test at Normal Pressure—The aneroid is placed in the thermal chamber and allowed to remain at a constant temperature of 20°C. for at least one hour. A comparison is then made between the reading of the aneroid and the true pressure, as given by the mercury barometer. The temperature of the chamber is then reduced and held at 0°C. for a further one hour. The reading is again recorded and compared with that of the standard barometer. After the chamber has been heated to 40°C. the aneroid is allowed to remain at this temperature for an hour, and another comparison made with the standard. A final comparison is made after the aneroid has stood at the original temperature, 20°C. for a period of three hours. Throughout this part the aneroid remains at a pressure approximately equal to normal pressure. (30 inches.)

Part 3. Calibration and Drift—The Calibration errors at normal temperature (20°C) are determined while the pressure is being reduced at the rate of one inch of mercury in five minutes, readings are taken at every inch of the scale. When the index has reached the lowest pressure intended to be read, the pressure is maintained constant for five hours. A second set of readings is then taken while the pressure is allowed to increase at the rate of one inch in five minutes. The drift is determined by the change in the corrections during the five hours interval.

Part 4. Temperature Test with Diminishing Pressure—The temperature test is divided into two portions, the instrument being calibrated in the thermal chamber at temperatures of 0°C and 40°C. Before calibration the instrument is allowed to stand at the temperature of test for three hours, the pressure being then reduced at the normal rate of one inch in five minutes. Comparisons are made between the aneroid and the mercury barometer at every inch. The results of the decreasing pressure test, Part 3, giving the calibration corrections at normal temperature, are taken in conjunction with this test.

Tolerances—The tolerances allowed in the above tests are as follows:

(1) The deviation by tapping shall not exceed 0.01 inch of mercury.

(2) The shift shall not exceed 0.01 inch of mercury.

(3) The vertical correction shall not exceed 0.04 inch of mercury.

(4) The proportional drift* shall not exceed 0.005 inch of mercury.

(5) When the calibration corrections at any temperature are ploted to scale, the average deviation of the points from the mean straight line drawn through them shall not exceed 0.02 inch of mercury, and the greatest deviation at any point from this line shall not exceed 0.04 inch of mercury. If the points lying above the mean straight line be taken as having positive deviation and points below the line negative deviation, the algebraic difference between the deviations of any two consecutive points one inch apart shall not exceed 0.03 inch of mercury.

(6) (a) The greatest variation in reading at normal pressure in the range 0°C to + 40°C shall not exceed 0.08 inch of mercury. (b) The greatest variation in reading at normal pressure in the range 0°C to 20°C or 20°C to 40°C shall not exceed 0.05 inch of mercury.

(7) The greatest difference in scale values† between 0°C and + 40°C shall not exceed 2 per cent.

(c) Adjustment of Gage Rate

In 1924 and 1925 there appeared an extensive correspondence on this subject in *Power*, a magazine which always shows interest in engineering instruments, and since there have not been placed on the market since then any gage movements differing from those discussed at that time, the author unblushingly admits his inability to shed any more light on the subject, and believes that the following abstracts may still be considered the "last word" on this interesting topic.

*"Proportional drift" is the amount of drift divided by the change in pressure producing the drift.

†"Scale value" is the mean value of one unit on the scale of the aneroid in terms of the true pressure change.

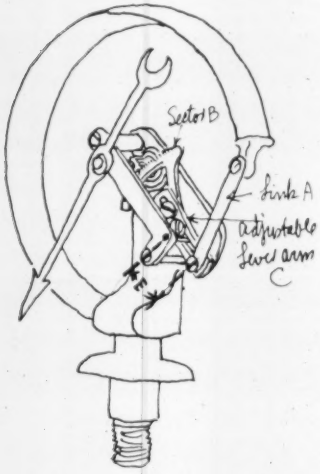


Fig. 331

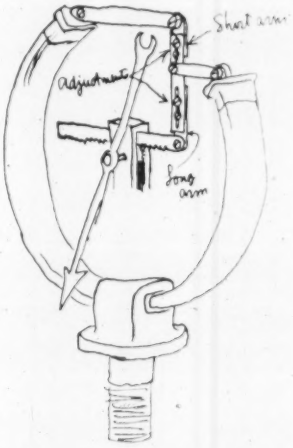


Fig. 332

Abstract of letter by Glenn E. Nichols, Rochester, N. Y.:

. . . The two general types of Bourdon gages in use are the single-tube and the double-tube. In these types the connection of the pointer to the gage tube is by some form of adjustable gear and lever mechanism. In the usual single-tube gage this adjustment, illustrated E on the sketch, Fig. 331, is generally one of three forms: (1) a slotted arm of the sector in which the end of the connecting link A from the gage tube can be moved; (2) a cam motion at the end of the sector arm to which lever A is attached; (3) a separate sector arm C that is fastened to the sector B by screws, this separate arm being slotted for the pivot pin. Thus a change by any of these methods will change the leverage E, which will cause a slower or faster movement of the pointer for any uniform increment of pressure.

In the double-tube type there are two adjustments as shown in the sketch, Fig. 332, one in the short arm and one in the long arm. The uneven variation that cannot be taken care of in the single-tube gage may be to some extent eliminated in this type.

Abstract of letter by R. Beck, Chief Engineer, American Schaeffer and Budenburg Corporation, Brooklyn, N. Y.*:

. . . A principle of adjustment for uneven spring deflection in single-tube gages consists in varying the angle ABC, where A represents the center around which the gear segment swings, B the point at which the connecting link L pivots on the segment and C the pivot in the endpiece at the other end of link L. Figs. 334 and 335 show how the angle ABC affects the working of the gage (conditions exaggerated for sake of clearness).

Fig. 334, AB is the position of the segment at zero pressure, AB_1 the position at maximum pressure. The shorter distances AD and AD_1 between A and the two link positions BC and BC_1 represent the effective lever lengths. It will be seen that AD is shorter than AD_1. For equal distance traversed by the spring endpiece C, the pointer will therefore move faster near position B than near position B_1.

Suppose now that length AB has been adjusted so that the pointer, for instance on a 100-lb gage, covers correctly the distance 0 to 100 lb but is too

*Now Consolidated Ashcroft Hancock Co., Bridgeport, Conn., where Mr. Beck is at the present time.

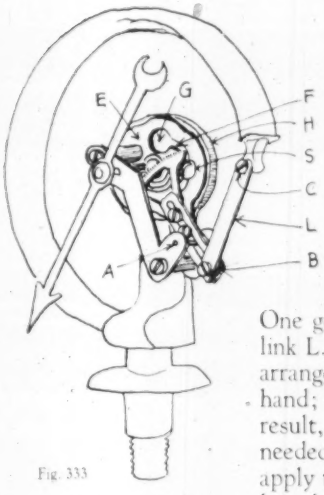


Fig. 333

low at 50 lb. It is only necessary to bring the movement into a position similar to Fig. 334, which will increase the speed in the first half of the scale so as to bring the pointer up to 50. Inversely, if the pointer had been too high at 50, the movement should be brought into a position similar to Fig. 335, which produces slow speed at the beginning and high speed at the end. There are several methods of obtaining the required adjustment. One generally used is to change the length of link L. In quantity manufacture it can be easily arranged to have links of assorted lengths on hand; if the first link does not give the desired result, it is replaced by a longer or shorter one as needed. The user of the gage, however, cannot apply this method. A new movement patented by the American Schaeffer and Budenberg Corp. eliminates the exchanging of links and can also be adjusted easily by the user. This movement has a round center plate E with two symmetrical slots F (only one visible in Fig. 333) through which the two movement fastening screws S are inserted. The enlargement G of the slots allows slipping the movement over the screw heads without removing the screws from the supporting plate. The slots allow a considerable a ngular adjustment of the movement, which permits the use of a single-length connecting link L, as the adjustment takes care of any variation in the location of the spring endpiece C.

The round bottom plate E has a small extension in its center (not visible in Fig. 333) which engages a hole in the supporting plate H and keeps the pointer shaft in exact alignment with the dial. Fig. 336 shows the effect of this adjustment. Suppose the first adjustment was a symmetrical BAB^1, and increased speed at the beginning is required; by loosening the two screws S and turning the movement so that A is shifted to A_1, a condition similar to Fig. 334 is obtained.

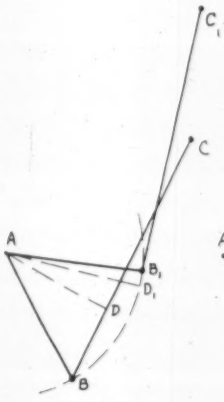


Fig. 334

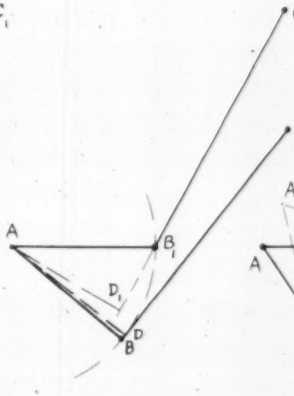


Fig. 335

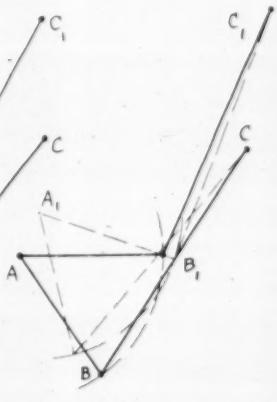


Fig. 336

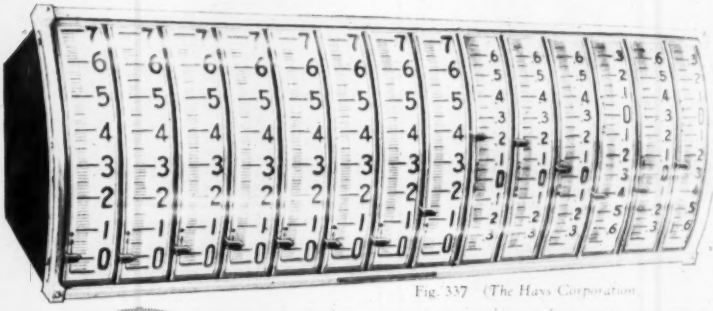


Fig. 337 (*The Hays Corporation*)

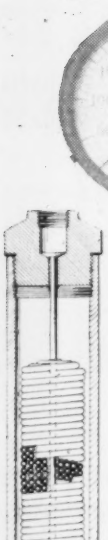


Fig. 339

Fig. 338
(*The Hays Corporation*)

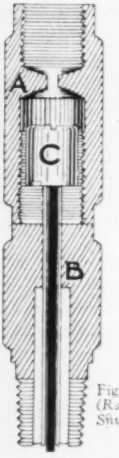


Fig. 340
(*Ray Pressure Snubber Co.*)

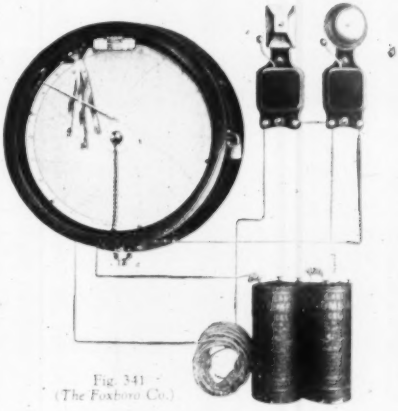


Fig. 341
(*The Foxboro Co.*)

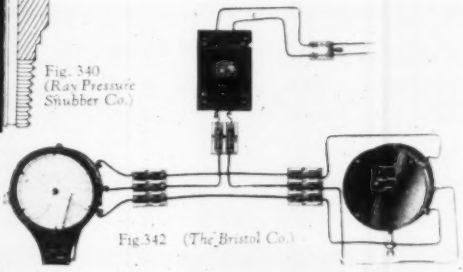
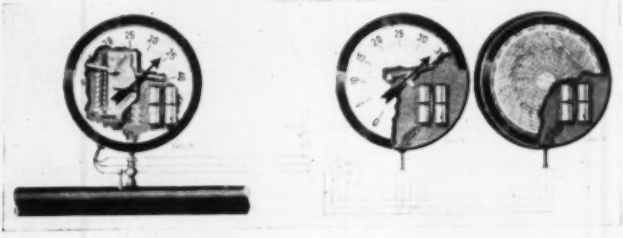


Fig. 342 (*The Bristol Co.*)

Fig. 343 (*Brown Instrument Co.*)



(d) Replacing Diaphragm Leathers

This can be done in many cases without returning the gage to the factory. But first ascertain whether the special grade of sheepskin known as meter leather may be used, or whether gold beaters' cloth or something like it is required. In many cases the leather will have to be blocked over a form so that it will not wrinkle and yet will have enough slack to allow free motion. A wooden forming pan for circular leathers can usually be turned on a lathe in a few minutes.

16. Miscellaneous Industrial Features and Accessories

The most important class of accessory devices is that which comprises devices for protecting gages against corrosive fluids or simply against the admission of water. It seems unnecessary to illustrate any of these, and beyond putting on record here an emphatic reminder of their frequent importance they need not be described.

Fluctuation deadeners are also on the market and often serve a useful purpose but on some applications they may cause misleading readings as explained in Chapter X, Sections 7 and 8. But on applications where it is satisfactory to obtain the "average" pressure their use is strongly recommended as conductive to ease of reading gages and diminution of wear of gage movements. Fig. 338 shows the section and Fig. 339 the general appearance of one kind. "The pulsating pressure from the line is forced to reach the gage through a considerable length of fine tubing coiled closely within the compression air-chamber. This 'air-receiver' action, combined with the friction of the fluid in the fine tuning, absorbs the fluctuations." Fig. 340 shows a section (3/4 actual size) of another kind, described in part as follows:

". . . The Ray Pressure Snubber has a traveling clearing pin, which keeps all sediment or foreign matter contained in liquids under pressure from entering the gage, as this clearing pin moves upward and downward on every pulsation, thereby forcing any foreign matter back into the line . . . The snubber is shipped with three different sized pins to take care of variation in bodies of fluids under pressure. Should the standard pin contained within the snubber not work as desired, one of the other pins should be inserted to meet existing conditions. The No. 1 pin for more freedom of action, or the No. 3 pin for a close reading on the gage, or to prevent the needle fluctuating at all. These pins are desirable as some mechanics like to see a gage needle pulsate slightly, while others desire an absolutely stationary needle."

Next to automatic control, any reliable means of signalling, by flashing lights or sounding audible signals, is desirable wherever men are instructed to maintain pressures within certain limits. A number of contact devices, for indicating as well as for recording gages, are available and Fig. 341 shows one kind.

Reference has been made to multi-pointer gages under the descriptions of various classes. Fig. 337 shows a multi-pointer gage with fourteen scales—which is by no means the practical limit.

In large plants and on other applications it is often desirable to locate pressure indicators or recorders at a distance from the point where the pressure is taken off, much greater than can be done by running a gage line. Several makes of trustworthy electrical distance systems are available. Two are shown in Figs. 342 and 343. In this connection it is not amiss to call attention to the difficulties and troubles that go with long gage lines. See Chapter X, Section 10.

Some of the hundred-odd illustrations in the foregoing part of this Chapter have already given some idea of the variety of instrument cases. Mention may now be made particularly of water-proof cases which should

Fig. 344 (*The Bristol Co.*)

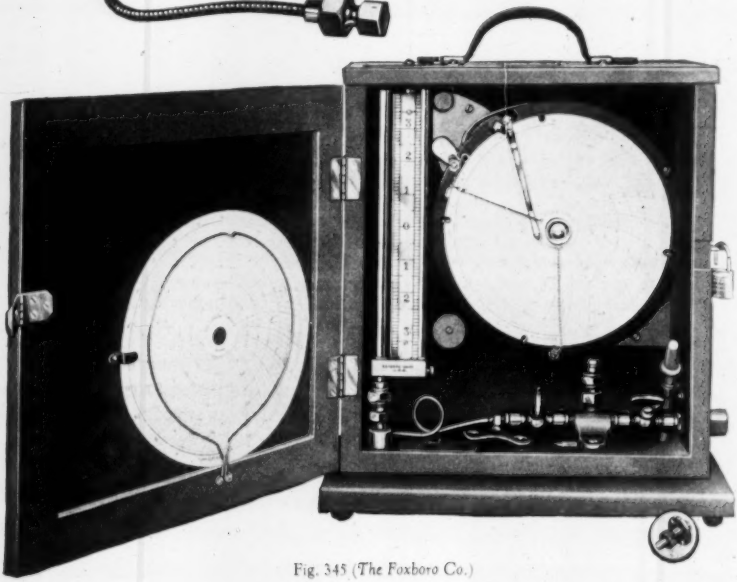


Fig. 345 (*The Foxboro Co.*)

often be specified but are generally overlooked. And the usefulness of portable pressure recorders, of which there are several distinctly specialized forms, among which those shown in Figs. 344 and 345, needs also to be stressed. A portable pressure recorder does not take the place of a Plant Standard for calibrating permanently-installed gages, but it supplements a number of indicating gages of corresponding ranges located on applications which, while not calling for the installation of recorders, call for the occasional taking of records as a check on processes, operators, etc.

Instrument Springs and Diaphragms

The Status of Experimental Knowledge of their Endurance, Elastic, Thermal and Other Properties Affecting Service-life and Accuracy

M. F. Béhar*

In considering the field of pressure instruments, one is struck by a strange paradox: On the one hand a great—and, growing—proportion of engineers manifest a preference for gravitational-method instruments that almost amounts to a prejudice against elastic-member instruments; on the other hand a great and ever-growing majority of the instruments sold every year for pressure measurement depend on curved flattened tubes, helical tubes, diaphragms, metallic bellows, springs of various shapes, and other elastic elements that deflect in proportion to the applied pressure.

Certain it is that easily read dials are preferable to visible liquid columns. Equally certain it is that perfect elasticity and total absence of hysteresis and variance have never been attained. All metals and alloys are subject to what is commonly called "fatigue." The best of springs fail sooner or later—some mysteriously soon, some "not yet" as in the case of the famous Ashcroft gage which, returned to the factory after nearly *eighty years*, was found satisfactorily accurate after re-calibration.

Evaluation of the properties of metals and alloys to resist *static* stress at *normal* temperatures has become a well-understood matter. But when it comes to methods of evaluation of resistance to *repeated* stress, to *abnormal* temperatures, or to *wear*, neither the methods of test nor the engineering application of the information are so well understood.

And with regard to the "service life" or "accuracy life" of elastic members, as distinguished from their life until actual failure occurs, there is very little information and there appears to be no accepted criterion, not even a set of accepted definitions.

In the meantime, it is a sort of free-for-all, in which any gage manufacturer can devise any test and proclaim that his product is "best by test," and it speaks well for the high ethical standards of instrument-makers that the endurance test advertisements actually published are not "raw." In spite of the increasing rapidity of progress in research on properties of materials and behavior of elastic members under various conditions, it probably will be all of ten or fifteen years before the situation is cleared up. Until then every engineer interested in these problems must do a lot of digging out for himself. Let us then proceed to summarize some of the important recent data and cite references.

*Engineering Editor.

(a) "Fatigue"

"How long will this part last?" is a question which the instrument designer often puts to metallurgical engineers, and one which is seldom easily answerable. The metallurgists and testing engineers will in turn put to the instrument designer some rather embarrassing questions in regard to the exact effects of the actual service to which the spring or other elastic member is to be exposed. *Users* of pressure gages could answer many such questions, but who is to direct such a survey? There is no "National Association of Users of Instruments Depending on Elastic Elements"... *but*—there *are* recognized engineering socities, and many readers of this book belong to them. The following pages may seem to paint a discouraging picture but their design is the opposite: to suggest and to stimulate.

The most readable by far—and one of the most erudite—of all the authorities on "fatigue" of metals is Dr. H. W. Gillett, Director of Battelle Memorial Institute and Editorial Director of *Metals & Alloys*. It is to him and to that publication that the author is indebted for the substance of the following discussion, as far as heading (*c*).

Most of the failures in moving parts made of metals do not come as a result of a smash-up, but are caused by the continued repetition of stresses so low that their effect would be inappreciable if they were not repeated. In these "fatigue" failures, even a ductile metal finally snaps off short, without distortion, because a crack has been produced, and is propagated till the cross section is cut down. Due to the appearance of the final fracture, mechanics long ago jumped to the conclusion that the "metal had crystallized under vibration" which it did not do at all. The type of fracture merely revealed the original crystalline structure. The "crystallization" myth has long obscured a realization of the true phenomenon.

The phrase "fatigue," too, is an inaccurate one. Metals do not get "tired," and then rest up. If they are repeatedly overstressed, they begin to develop very tiny sub-microscopic nuclei for failure that in time develop into cracks. "Endurance" or resistance to progressive failure under repeated stress, is a far better term than "fatigue," though "fatigue" is so firmly entrenched in our vocabulary, that it will be a hard term to get rid of. Ten years ago, the state of knowledge of the endurance of metals under repeated stress was fully as chaotic as it is today in regard to corrosion, wear and high-temperature service. There is, of course, much more to be learned, but a good many of the fundamental principles are now well understood.

The subject was first studied about 1852 by Wöhler in Germany. One of his tests ran over 132 million cycles at 72 r.p.m., i. e., it took 3½ years. He spent 12 years in these researches, and died at the age of 94. In modern times, it has been found necessary, on some alloys, to extend the test upward of 500 million cycles. The useful life of many moving parts has to be measured in billions of cycles. One can't tell how an alloy will act in a billion cycles unless he runs it a billion cycles.

As research on endurance progressed, it finally appeared evident that steels, and ferrous alloys in general, have a true "endurance limit." That is, there is some stress below which, no matter how many times the metal is subjected to stress, it is not damaged, and will not fail. It was scarecely ten years ago that this was proven beyond question, and arguments ceased as to whether any stress, however small, if often enough repeated, would not cause failure. With certain limitations as to presence of internal stress, it is nowadays believed that if a steel specimen runs at a given repeated stress for ten million cycles without breaking, it will never break under that stress.

Belief in this fact is bolstered by the peculiar phenomenon of "strengthening by understressing." If a specimen is subjected to a few million cycles of repeated stress just below the endurance limit, it becomes strengthened and hardened (as can be shown by static tests), acting as if it were coldworked, though its dimensions do not change measurably, so that after this treatment it will stand many millions of cycles at repeated stresses so high that if it had not been for the preliminary treatment, it would have failed in a few hundred thousand cycles. With this fortunate fact in view, one can feel confident that a stress can be found at which steel will endure indefinitely, if corrosion or surface damage be prevented, and if temperature be within "normal" range.

As long as the stress is below the endurance limit, no damage will ensue. If, on the other hand, the stress is allowed to rise above the endurance limit, damage is done. Hence, the endurance limit is a stress below which everything is lovely, and *the metal is getting better*

instead of worse, but above which damage is being done. This damage may be so slight that it will take millions of cycles to develop it into a crack and consequent failure, but damaged it is, nevertheless. Hence, it is highly important to guard against the possibility of even a few applications of load over the endurance limit.

It can hardly be too strongly emphasized that the endurance limit is a *stress* value. Very often the *design* value of the stress is low, but the *actual* stress value, at a sharp shoulder, a key-way, or a screw-thread, for example is actually way above the calculated value. The metal will fail if at any point, however minute, repeated stress is applied above the endurance limit.

The straight endurance limits of steels are (given a properly shaped and polished test bar, with freedom from external notches such as scratches on the surface or internal ones such as inclusions, slag streaks, shatter cracks, etc.) pretty much proportional to the tensile strength or the Brinell hardness. The ratio of endurance limit to tensile strength is around 50:100, though it may be as low as 35:100 or as high as 65:100, so that one cannot dispense with the direct determination of the endurance limit. That is, if only service, without abuse, were to be in the picture, the stronger the steel can be made in tension, the higher its endurance limit. But this approximation doesn't hold even on the basis of the regular endurance test alone, for quenched, heat-treated steels drawn at so low a temperature or for so short a time that internal stresses are not released.

Even when internal stress can hardly be blamed for the effect, it turns out, in service, that a softer, tougher steel acts better than the one that would be picked from an endurance test alone. This doesn't mean that the information given by the endurance test is wrong, it merely means that it gives one kind of information. So if the service involves only occasional overload, as well as repeated stress at the design load, or if surface notches are to be allowed, (thus raising the stress from the design value to an unknown but higher value,) the engineer must temper his enthusiasm for superhard steels which will not stand shock, and are sensitive to the notch effect.

An endurance test is made by running a specimen at a high stress till it breaks and noting its life, running another at a lower stress, and noting its life, and so on, at progressively lower stresses, till the specimens cease to break and run for as many millions or billions of cycles as it has been decided to extend the test. The stress-life (S-N) curve is then plotted, and if the curve is truly horizontal and parallel to the N axis, then the endurance limit has been found.

The old "vibratory test" in which a specimen was subjected to repeated stresses so high that it broke in, say a few thousand alternations of stress has been, or at least should be, abondoned, because the S-N curves, above the endurance limit, may cross, and such tests may not even rate competing materials in the proper order. The search nowadays is for the safe stress—the endurance limit—and finding it involves running some specimens for a long, long time *without* fracture. Many attempts have been made to find something, like the development of heat in the specimen due to slip, a change in electrical resistance, or some other property that would, in a relatively few cycles, tell whether anything was occuring that would ultimately cause failure. But the development of the nuclei for failure into perceptible cracks comes so slowly that such methods are yet unavailing.

The obvious way to let the nuclei develop, and still get the test done in a hurry is to use a great number of cycles but apply them awfully fast. Hence, various schemes are being used to speed things up. Magnetic type testing machines are being run at 30,000 cycles per minute and airdriven specimens are being made to vibrate of themselves at great speed, something like a tuning fork. (See October, 1929, issue, *Metals and Alloys.*) Unfortunately, the problems involved are extremely difficult. The methods would give results unsafe for design use unless a correction factor can be found, and the establishment of a correction factor entails recourse to the old, tedious, slow speed methods.

It does seem possible to speed up the testing somewhat, as McAdam has reported normal results with tests run at 10,000 r.p.m. instead of the usual 2000 r.p.m. or less. But great care has to be taken in speeding up any given testing outfit, to see that no harmonic vibrations are set up that impose actual and unknown, stresses on the specimen above those calculated. Incidentally, harmonic vibrations must be just as carefully guarded against in practice. Three of the four crankshafts of the Graf Zeppelin broke during one of the early trips because, when in actual use in the dirigible, harmonics were set up that were not present in block testing, with a rigid foundation, and whose presence, was not suspected till too late. This is a *known* case. How many hundreds of pressure gage springs have failed for analogous reasons, no one knows!

Between the standard laboratory test on a notch-free, perfectly polished specimen of spring steel, and the results in service, there is quite a gap. Rough surfaces the presence of bolt holes, surfaces decarburized in heat treatment and not removed, or the presence of corrosion, will all drop the calculated stress that the spring will withstand, far below the laboratory

value. This fact points out obvious means of improving instrument spring design and fabrication so that the steel may have a chance to act as it does when it is on its good behavior. The amount of surface notching the steels will stand when they are abused, needs much further study. There is good evidence that internal quenching stresses adversely affect the endurance of heat-treated steels, and it takes longer tempering to remove such stresses than is usually given. Different alloy steels probably vary greatly in their susceptibility to surface notches or to internal ones, i. e., inclusions as well as in their ability to attain relief from internal stress without softening too far. These matters deserve more attention than they are getting.

In spite of all the drawbacks the need for the results of endurance testing is so plain and the value of the results so great, that vast amounts of research have been put on the problem in America, England and Germany.* In America, in addition to Dr. Gillett, R. R. Moore, D. J. McAdam, Prof. H. F. Moore and co-workers at the University of Illinois, and J. B. Johnson at the Army Aircraft laboratory at Dayton, various workers at the Bureau of Standards, at the Research Laboratories of the Westinghouse Company, the Bell Telephone Company, the Aluminum Company of America, (see September 1929, *Metals and Alloys*) the General Electric Company, the National Tube Company, the University of Wisconsin, Lehigh University and others, have covered the field very thoroughly. The results have been well substantiated by data from an almost equally long and brilliant list of English investigators.

(b) Endurance Limit—A Few Figures.

While it is impossible to list here anything like the range of alloys on which endurance data are available, a few representative figures may be given. Data on wrought steel is best considered from the point of view of a comparison with the static tensile strength. Ingot iron has an endurance limit, in completely reversed bending of around 60% of its tensile strength (even though this is above the proportional limit). As the carbon increases, in annealed or normalized steel, those of .10—.15% C usually run about 50% of the tenile strength, but as the carbon increases further the endurance ratio tends to drop to around 40%, and figures as low as 28% are recorded.

Raising the carbon does raise the endurance limit, in absolute value, but it is not the most effective way of improving the endurance properties. Cold working, again, raises the endurance limit, in absolute value.

When high endurance is required, quenching and tempering of carbon or alloy steels is generally resorted to. If the steels are clean, as free as possible from non-metallic inclusions, shatter cracks or internal strains, the endurance limit stays at 45-55% of the tensile strength, up to a tensile strength of about 200,000 lb. per sq. in. Above that strength, as with steels of say 275,000 lb. per sq. in. tensile, the endurance ratio is likely to be lower, and the endurance limit seldom rises much above 110,000 or 115,000 lb. per sq. in., probably through the effect of internal stress. Prolonged tempering at low temperatures so as to maintain a high tensile strength has sometimes allowed the production of specimens with around 125,000 lb. per sq. in. endurance limit.

While there seems to be a tendency for the endurance ratio to be higher in a sorbitic steel than in a pearlitic one, the presence of troostite, martensite or austenite does not notably affect the endurance ratio. The austenitic stainless steels show about the usual 50% endurance ratio and the endurance limit in completely reversed bending may be well above the proportional limit, as is the case with pure ferrite.

Carburizing or nitriding offers distinct possibilities for service where the maximum stress is at the surface. Carburized steels can be made to give 55,000 lb. per sq. in. endurance limit, and a nitrided steel has given as high as 84,000. There is always a danger of starting a notch in a brittle coating which will reduce the endurance limit, and the brittle iron-zinc alloy layer on a hot-galvanized or sherardized steel is responsible for reducing the endurance limit from 60,000 to less than 45,000 lb. per sq. in.

*The designer can get the gist of the endurance situation from a concisely-written "Manual of Endurance of Metals Under Repeated Stress," by H. F. Moore (Engineering Foundation, New York, 1927). The Fatigue Research Committee of the American Society for Testing Materials made a report in June, 1930 in which the accepted facts as to endurance of metals are briefly and clearly stated. For a more extended discussion of the subject, two books with the same title, "The Fatigue of Metals," one by H. F. Moore and J. B. Kommers (McGraw-Hill Book Company, New York, 1927), the other by H. J. Gough (Van Nostrand, New York, 1924) are available. Both of these contain tables that summarize the known quantitative facts on many engineering alloys. The individual original researches from which the present situation can be pieced together, are published, in this country, largely in the Bulletins of the Engineering Experiment Station of the University of Illinois, and in the Proceedings of the American Society for Testing Materials. The A.S.T.M. published in 1929 (and plans to do so in 1931) a collection of abstracts on the literature of endurance. Such abstracts appear month by month as the articles are published, in *Metals and Alloys*.

With ferrous materials it is always necessary to recall that when corrosive conditions of service are involved, they all tend to come down to a much lower corrosion-fatigue limit, no steel that is not truly corrosion-resistant having a corrosion-fatigue limit much over 25,000 lb. per sq. in. and often lower. Heat-treatment is not of much value in this connection. Even stainless steel has its endurance limit rather badly reduced, while the austenitic stainless type, truly corrosion resistant under most service conditions, loses but little in endurance limit even though corrosive conditions obtain.

The situation in regard to non-ferrous alloys is very complex. The endurance limits are generally rather low, and the effect of cold working is not always of particular benefit. Alpha brass, for example, has its endurance scarcely raised at all by cold working. Some non-ferrous alloys of 90,000 lb. per sq. in. tensile strength have endurance limits under 15,000 lb. per sq. in.

Nickel and especially monel metal, though probably not having a real endurance limit, yet will stand, on a basis of a 500 million cycle test, 25,000—35,000 lb. per sq. in.

Most of these non-ferrous alloys are corrosion resistant, and have fairly respectable corrosion-fatigue values.

Heat-treated duralumin shows some peculiarities in endurance, different lots acting differently for no apparent reason. In general, the endurance limit, though none too well marked, is generally taken as around 15,000 lb. per sq. in. on a 500 million cycle basis.

(c) "Dynamic Ductility"

While the endurance limit is the most important property of elastic materials, lending itself to accurate determination, and the effects of temperature on which are likwise subject to methodical study, some other properties have not yet been satisfactorily defined. Among them are properties of greater importance to the instrument user than the endurance limit—some that determine the performance of a spring as the *measuring* element of an instrument under normal conditions of use—such properties, of course, as hysteresis effects.

As a matter of fact the rational definition of one such property has not yet been published and it was only through a stroke of pure luck that the author stumbled upon the manuscript of a little treatise which gives it for the first time. This treatise will probably be published next autumn, until which time one is not permitted to name its source. In this paper, the property in question is called "Damping Capacity or Dynamic Ductility or Hysteresis Effect"—its joint discoverer is as undecided about naming it as he is certain of having tracked it to its lair. Dynamic Ductility is our choice, because it is related to the dynamic behavior of elastic-member instruments.

Whatever term is decided upon, it is bound to achieve recognition while the "laws" of elasticity which we were (and still are) taught in engineering schools will accompany obsolete manuals to the garbage dump. For this is a mighty important property. One may say that the endurance limit is the most important property of elastic *materials*; the modulus of elasticity that of *springs*; and Dynamic Ductility that of *instrument* springs.

In the treatise to be published within a year, five graphs and nearly 1000 words are required for its complete definition, as distinguished from static ductility, etc. In brief, it *seems* (the present writer is not up on these recent researches) to be the measure of the plastic deformation that occurs within the "service range"—which means, as is proved in the treatise, that Hooke's law is a mere approximation and that there is no such thing as an "elastic" material. This is not unreasonable: we all know that the best tempered spring soon stops oscillating even in a vacuum. Obviously there is plastic deformation, like when you bend a lead wire, but infinitely less. Obviously there is, within the "elastic" range, a small but at last measurable amount of *work*—which "vanishes" or is changed to heat. This work is that which is needed to make possible the plastic deformation.

This work is represented by the area between the straight line of Hooke's law and the actual stress-strain curve obtained by the new methods, in a complete cycle from $+S$ to $-S$. This is a figure-eight and it is nothing other than a hysteresis loop.

We have seen above, under "Fatigue," that the "straight endurance limit" is determinable in S-N terms. The great advantage, now, of going by Dynamic Ductility is that it considers only performance *within* the perfectly safe range—and not over billions of cycles but over a number of $\pm S$ alternations enough to give concordant results—say half a dozen.

The new method is based on measuring the amount of work represented by the elastic hysteresis loop. The value determined is ψ, a dimensionless value whose expression is $\frac{\delta}{A}$ where δ is the hysteresis work and A the modulus of resilience. ($A = S^2/2E$ where E is the conventional modulus of elasticity).

If this extra-condensed résumé lacks clarity, the author hereby ventures a brief (if perhaps vaguer) definition, in terms for instrument men:

Dynamic Ductility is that property which determines the variance of a free spring.

(d) Drift and Hysteresis Definitions

One excellent reason for rejecting the term "Hysteresis Effect" for the above-discussed property is that there are two types of hysteresis of instrument elastic members are already recognized by the Bureau of Standards, in addition to drift or creep which is not hysteresis:

Drift or *creep* is the increase in the deflection of an elastic body with time when kept under a constant load. As a consequence of drift the instrument fails to return to zero. The departure is roughly the same as the drift. Data on the value of drift for various spring and diaphragm materials and its relation to such factors as stress and time are incomplete. The efforts of individual manufacturers have been directed toward using the best of the materials now available and they have in large measure restricted their tests to securing enough information to meet a given problem. In practically no instance have their findings been published. Experimental work should be continued in order to determine more completely the drift phenomena of metals and alloys which might prove useful in the elastic systems of instruments. The chief need is for dependable experimental data. As an illustration elinvar might prove useful as a diaphragm metal owing to its low temperature coefficient of elasticity if experiment showed that the drift and other elastic defects were within permissible limits.

Hereditary hysteresis—This term is applied to the hysteresis occurring in a load cycle, owing to the drift of the elastic body. It is therefore dependent upon the time taken in making the load cycle. It is obvious that the values of hereditary hysteresis are dependent upon the values of the drift.

Statical hysteresis—This is the hysteresis in a given load cycle which is independent of the time. It is measured when the material under test is in a "cyclic" state, which is secured by first subjecting it to a number of load cycles.

The small value to which the elastic hysteresis can be reduced in instruments is surprising. Taking the altimeter as an example, the tolerance a few years ago for the ratio of the maximum hysteresis in a cycle to the altitude range was one per cent. At the present time a number of manufacturers have produced instruments which have a maximum hysteresis ratio of 0.1 per cent.

(e) The A. S. M. E. Special Research Committee

The output of literature on elastic properties, in the form of books and of articles in technical journals, has now reached such a volume that merely to keep up with these sources takes an engineer's entire time. In addition, meaty official reports of wholly original researches come out more frequently than ever in the past. Two types of research on elastic and inelastic behavior of springs are being carried on: fundamental and practical. Various investigators are at work on each. Both types are carried on under the auspices of several institutions, notably under those of the A. S. M. E. Special Research Committee on Mechanical Springs, of which J. K. Wood is chairman. This committee has already presented seven Progress Reports.

All of these, and especially No. 7 presented at the December 1930 meeting of the A.S.M.E., contain new data ("startling discoveries" in journalese) which compel revisions of some of our concepts and "laws" of elastic properties to an even greater extent than the results of the special research referred to above under "Dynamic Ductility." Engineers interested in improving the performance of elastic-member instruments will do well to obtain these Progress Reports—especially those to be issued in 1931 and subsequent years.

Important work has been done by Prof. M. F. Sayre and associates at Union College, on steel, phosphor bronze and aluminum alloy wires. These were "only" subjected to tension

but the gage length of the specimens was increased to 52 feet so that readings of elongation were taken to one part in fifteen million; the temperature was closely controlled and the loading was done with precision, so that the accuracy was to one part in one million.

Sayre's tests indicate that the elastic limit and the proportional limit do no coincide, and that *the true stress-strain line*, aside from any plastic flow or hysteresis effects, is CURVED THROUGHOUT. Definite quantitative values for the rate of change of modulus of elasticity with stress intensity were obtained. Figures are also given by Sayre which indicate, for certain steel specimens, a marked increase in hysteresis and decrease in modulus of elasticity as a result of temporary overstressing beyond the elastic limit.

In the latest Progress report, mentioned above, Sayre gives numerical values for the *rate of change* of Young's Modulus of elasticity *with stress*. There is reasonably strong evidence that these same equations hold both in tension and in compression, although it has not yet been possible to obtain direct verification in compression.

The practical effect of this change of modulus as applied to spring design and manufacture is as follows:

(*a*) True stresses in compression are somewhat higher, and in tension somewhat lower, than the values given by the usual formulas. A sufficiently close approximation to numerical results may be obtained by first computing the maximum stress by the usual formula, and determining the per cent difference between the corresponding modulus of elasticity and the modulus as of zero stress. The percent error in stress will be 70 to 75 percent as great as the per cent difference in modulus.

(*b*) The increasing stiffness in compression with increasing stress more or less completely counterbalances the decreasing stiffness in tension, so that apparent stress-deflection curves in bending or torsion will be almost unaffected by the variation in modulus.

(*c*) In high-strength, highly elastic materials, such as are used in springs, it may be desirable, when selecting values of elastic limit from tensile stress-strain results, to make allowances for the curvature.

The Schenectady Tests have confirmed the general principle of a decrease in modulus of elasticity in tension as a result of previous overstrain in tension. This is an important reason for more or less erratic variations in stiffness of springs resulting from overstrain. It also appears to be an important reason for a hidden safety factor in design, in that it causes the true stresses in highly overstressed areas to be appreciably smaller than the computed values. The amount of this decrease in modulus with overstressing is evidently different for different materials, and naturally depends upon the previous history of the material. It is therefore difficult to give numerical values, except in general terms.

An article in Japanese published last year by Tadashi Kawai (*Kinzoku no Kenkyu*, 1930, no. 7, pp. 177-201; abstract in the *Journal of the Institute of Metals*, vol. 43, p. 430) describes an extended study of this effect.

Of particular interest to designers are the following remarks by Sayre in Progress Report No. 7 (the italics are ours):

"Certain other difficulties also inhere in the nature of the materials themselves. For the purposes of this work it was desirable to distinguish as far as possible between the elastic elongation, which occurs instantaneously or nearly so; the plastic elongation or 'permanent set,' which is a function of time, but apparently an irregular function, *sometimes stopping then starting again with but little evident cause;* and the elastic or pseudo-elastic after-effect, a *gradual* elongation *on loading*, followed by as gradual a recovery to original length *on unloading*.* It is accompanied by mechanical hysteresis or 'back error,' *but the two seem to be more or less independent in character*."

(f) Temperature Errors with Spring and Diaphragms

Years more might have passed without thorough research on the temperature coefficient of the modulus of rigidity of pressure instrument springs; but the life-and-death importance of such springs in the pressure instruments used on aircraft has led at last to the issuance by the National Advisory Committee for Aeronautics of Report No. 358 on that subject, by Drs. Brombacher and Melton.

This is only a starter, since the investigators report only on torsion pendulum experiments and since under their conditions of experimentation the effects of internal damping were negligible. Liquid bath temperature experiments on actual springs are to be reported on in

*An investigation of the characteristics of this elastic after-effect has been started and the results will presently be reported by the Committee.

future. We believe that even more light might be shed on the subject by devising conditions of experimentation that would show up the effects of internal damping. The only way to tell is to try. The report is so recent that the following extracts (in which the italics are ours) may be news—in more ways than one.

The temperature coefficient m is defined by the relation

$$m = \frac{1}{G_0}\frac{dG}{dT}$$

in which G and G_o are the moduli of rigidity at the temperatures $T°$ C and O° C. The differential dG/dT was found to be a constant except for two metals. The effect of heat treatment on m was determined for a number of the materials. It was observed that tensile stress affected the values of the modulus by amounts of 1 per cent or less.

. . . It is well known that the indication of an instrument depending upon the deflection of an elastic element, such as a diaphragm or spring, varies with temperature in properly designed instruments *the major part of this variation is due to the variation of the elastic moduli with temperature* . . . There are no data on many of the commonly used alloys . . . A very important point is that for the most part investigators have secured data on annealed specimens, while the elastic elements of instruments consist of hardened materials . . . Values of the temperature coefficients of elasticity are not given in current handbooks of physical data.*

. . . This paper gives the results of experimental work thus far completed at the Bureau of Standards. The data include (*a*) values of the temperature coefficient of the modulus of rigidity of a number of common materials, (*b*) values of the rigidity modulus at 0 C., and (c

*But see references at end of this section.

TABLE XX—TEMPERATURE COEFFICIENT OF THE MODULUS OF RIGIDITY IN TEMPERATURE RANGE −20 TO +50°C.

(Brombacher and Melton, N. A. C. A. Report No. 358)

Material	Composition, per cent	Condition of specimen	Temperature coefficient,[1] $\times 10^{5}$
Aluminum		Annealed	−100 to −135
	Al 99.5	Half-hard	−62
Duralumin	Cu 4.1	Heat-treated	−62
		Unknown	−46
Monel	Cu 26, Ni 70.2	Hard-drawn	−42
	Cu 28.9, Ni 67.7	Annealed	−38
Brass	Cu 63, Zn 35, Pb 1.8	Hard-drawn	−52
	Cu 62, Zn 35, Pb 2.6	do	−46
	Cu 60, Zn 40	Unknown	−40
Phosphor bronze	Sn 3.9	Hard-drawn	−48
	Sn 7	Unknown	−34
Coin silver	Cu 8.8	Hard-drawn	−56
Nickel silver	Cu 57, Zn 26, Ni 15.5	do	−44
	do	Heat-treated	−36 to −42
	do	Tempered at 200°C.	−42
Drill rod steel	C 1.38	Heat treated	−23 to −24
Oil tempered steel	C 0.70	Heat-treated spring wire.	−33
Piano wire	C 0.86	do	−37
	do	Hardened	−42
		Annealed	−26
Chromium vanadium steel.	C 0.55	Heat-treated	−26 to −34
	do	Quenched, tempered at 300°C.	−31
	C 0.50	Unknown	−30
	do	Hardened	−35
chromium molybdenum steel.	C 0.54	Unknown	−48
	do	Hardened	−40
Stainless steel	C 0.81	Quenched, tempered at 200° to 500 C.	−31 to −32
	do	Quenched, tempered at 600°C.	−23

[1]All values in this column to be multiplied by 10^{-5}.

to a limited extent the effect of tension, and (*d*) of heat treatment. The temperature range in which data were obtained was from −25° to +50° C.

The available data for aluminum and Monel metal indicate that the temperature coefficients of elasticity are independent of temperature within the experimental error when these materials are in the hard-drawn condition, but vary with temperature when annealed. All of the nonferrous metals tested in the hard-drawn condition had values independent of temperature. It is offered as a tentative conclusion that hard-drawn and annealed nonferrous metals generally show this difference in the temperature coefficients.

Table XX† summarizes the present state of knowledge on the temperature coefficient of the modulus of rigidity of the materials considered in this paper for the temperature range −20 to +50° C. The results of all investigators of these materials whose work has come to our attention were given due weight in determining the values given. The values are tentative in many cases.

†Table VIII in the original report.

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INSTRUMENTS BOOK SHELF

The books reviewed in this section can be supplied by the Instruments Publishing Company.

Regler fur Druck und Menge. By *Guido Wunsch*. R. Oldenbourg, Munchen, 1930. Cloth 8¼ x 5½ inches, 207 pages. Price 13 RM.

The author of the book, the chief experimental engineer of the Askania regulator works, has prepared this work to serve as an aid to the operating engineer who has to use regulators in the operation of his plant.

The object of the author was not to prepare a text book for the study of regulation, but to show how and when regulators are to be used and how they are to be operated. It may be remarked, however, that in the case of pressure quantity regulators for gases and liquids, the book may be considered fully as a text for the study of the subject. This kind of regulation is treated fully in every respect.

The pressure volume relation in throttling devices is given in explicit terms and is demonstrated by various sketches and curves. Special emphasis is given to the limiting capacity of those devices in actual operation. Details are included of practically all designs of pressure and volume regulators manufactured in Germany.

The book is recommended not only to the user of regulating devices but also to those interested in the manufacture of mechanical and electrical pressure or volume regulators.—J. M. Spitzglass

Measurement of Air Flow

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CHAPTER VII (Cont'd

Case 1—Mechanical Friction Neglected.—Let PQ (Fig. 38) represent one blade inclined at an angle θ to the wind direction RO, and let O be the centre of pressure of the blade. It should be noted that the blade is rotating in a circular path perpendicular to the plane of the paper, and that at the instant under consideration the blade is at the top of its path and moving

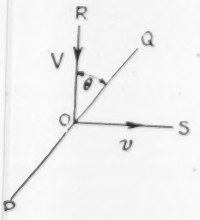


FIG. 38.

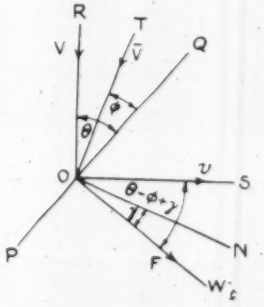


FIG. 39.

to the right with a velocity v along OS, perpendicular to the wind direction. The blade speed v will be such that the resultant of V and v lies along QP, and there will be no resultant force perpendicular to the plane of the blade,

$$\left.\begin{aligned} \text{i.e.} \quad & v = V \tan \theta \\ \text{and} \quad & N = Cv = CV \tan \theta \end{aligned}\right\} \quad . \quad . \quad . \quad (3)$$

Case 2—Mechanical Friction Included.—The velocity diagram when mechanical friction is taken into account becomes more complicated, and it is necessary to consider the forces acting on the blade. PQ (Fig. 39) will still move along OS, perpendicular to the wind direction, but at a lower speed v such that the resultant of V and v, i.e. the wind speed $\bar{V}$ relative to the blade, will now, when the motion has become steady, be inclined at an angle ϕ to the plane of the blade. The blade

thus becomes a flat plate inclined to the wind at an effective incidence ϕ, and there will be a resultant force F on the blade acting along OW, inclined at an angle γ to ON, the normal to the relative wind direction. The component of F along OS, multiplied by the distance of O from the axis of rotation and by the number of blades, provides the torque which overcomes the resisting torque due to mechanical friction.

If, therefore, we neglect any change in velocity of the wind during its passage through the vane circle, and any interference effect which one blade may exercise on its neighbours, we may use equation (1) to give us, for the blade under consideration, the following equation for F :—

$$F = K\rho V^2 A\phi.$$

Resolving along OS, putting $V^2 = V^2 + v^2$, and equating the wind torque to the frictional resisting torque, we therefore have for steady motion,

$$T = K\rho\phi A(V^2 + v^2)mr \cos(\theta - \phi + \gamma). \quad . \quad . \quad (4)$$

Also, from the velocity diagram,

$$v = V \tan(\theta - \phi). \quad . \quad . \quad . \quad (5)$$

We shall find it convenient at this stage to consider the practical aspects of the equations so far derived. It will be apparent that the speed of rotation of a given set of vanes will be determined not only by the wind speed, but also by the mechanical friction introduced by the spindle bearings and also by the gearing. In the ideal case where friction is entirely absent the calibration curve of the instrument, i.e. the curve of indicated wind speed against true wind speed, would be a straight line passing through the origin—see equations (3)—whose slope would be determined (once the gearing ratio is fixed) by the inclination of the vanes to the wind direction. In practice, however, friction exercises an effect which is felt mainly at low speeds when the aerodynamic forces on the vanes are small. At high speeds, when the relative effect of friction is small, ϕ becomes small compared with θ, and we see from equation (5) that the calibration curve of the instrument will be practically linear. At low speeds ϕ is comparable in magnitude with θ and v will be zero at a certain low value of V when ϕ becomes equal to θ.

Actually the behaviour of all well-made anemometers fully substantiates the above reasoning. The usual type of calibration curve for such instruments is illustrated in Fig. 40. At high speeds the curve exhibits no sensible departure from linearity, but at low speeds it bends over somewhat in the

manner shown, the abscissa OA representing the true wind speed at which the vanes just begin to turn, that is the limiting speed at which ϕ becomes equal to θ. The magnitudes of the wind speeds corresponding to OA and to OB (above which the curve is linear) vary, as is naturally to be expected, with different instruments; in the author's sensitive low-speed anemometer, to which reference has been made above, OA was found to be about 0·6 and OB about 1·0 feet per second.

The friction torque T in equation (4) cannot be computed

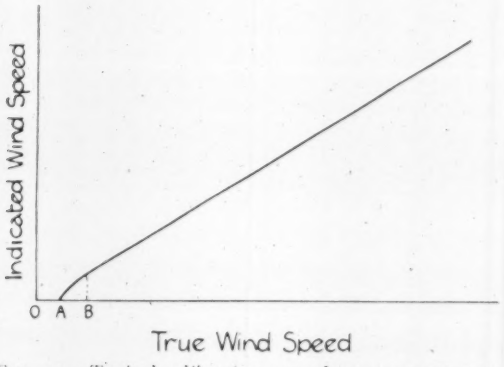


FIG. 40.—Typical calibration curve for vane anemometer.

from first principles; it will obviously depend upon the construction of the instrument, and so will have to be determined separately for each anemometer by experiment, if a knowledge of its magnitude is required. The necessary tests, however, are simple, consisting, as they do, only of a calibration to establish the relation between v and V for a number of values of the wind speed V. The torque T for a given speed V can then be calculated by the use of equations (4) and (5), v being taken from the calibration curve, and the values of K and γ being obtained from Figs. 36 and 37 at the values of ϕ calculated from equation (5).

Now the torque T is made up of two components, one due to the weight W of the moving parts, and one due to the end thrust of the spindle on the rear bearing, arising from the component P of the resultant wind force acting along the wind direction. Hence we may write

$$T = \mu W r_1 + \mu P r_2, \quad . \quad . \quad . \quad (6)$$

where μ is the coefficient of friction, and r_1 and r_2 are the effective radii, whose actual values do not concern us, at which the forces μW and μP act.

If, as is generally the case, the bearings are cylindrical,

it is justifiable to regard r_1 and r_2 as constant. If, further, we assume that μ is constant, we may, since W is constant, write (6) in the form

$$T = g + hP, \quad . \quad . \quad . \quad . \quad (7)$$

where g and h are constants.

T is given by equation (4) and can be calculated from the calibration curve, as already shown. Similarly, P will be given by

$$P = K\phi\rho A(V^2 + v^2)\, m \sin(\theta - \phi + \gamma), \quad . \quad (8)$$

and is calculable in an analogous manner. From (7) we may expect a curve of T against P to be a straight line, from which the values of g and h can be determined. Values of T and P for the low-speed anemometer previously mentioned have been calculated and are plotted in Fig. 41. It will be seen that, except for the small values near the origin—corresponding to values of V below 1 foot per second—the points lie well on a straight line, which gives values of g and h of $1{\cdot}6 \times 10^{-6}$ and $8{\cdot}0 \times 10^{-2}$ respectively. The departure from linearity at low speeds may be due to a variety of causes which are discussed more fully below.

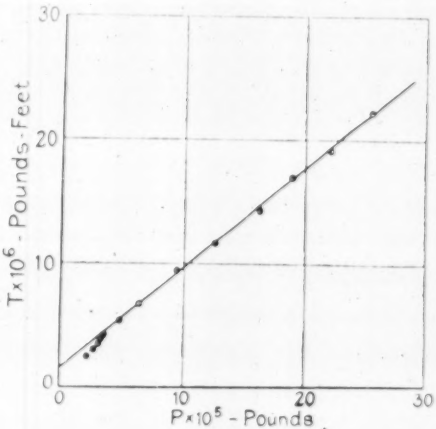


FIG. 41.

The values of T and P plotted in Fig. 41 are given in the following table. The mechanical constants of the instrument

TABLE VIII

Wind Speed V, Feet per Second.	$T \times 10^6$ Pounds-Feet.	$P \times 10^5$ Pounds.
0·59	2·46	2·17
0·7	2·98	2·67
0·8	3·42	3·02
0·9	3·85	3·34
1·0	4·18	3·57
1·5	5·39	4·86
2·0	6·69	6·40
4·0	11·82	12·60
6·0	16·95	18·98
8·0	22·20	25·60

to which they relate are as follows :—

$A = 0{\cdot}0068$ sq. ft. ; $r = 0{\cdot}115$ ft. ; $m = 8$; D = 0·312 ft.
$\theta = 45°$; gear reduction (vanes to pointer) = $\frac{1}{240}$.
$I = 192 \times 10^{-8}$ slugs-ft. units.

Effect of Variations of Air Density.—We may turn now to a consideration of the effects of variations of atmospheric density on the readings of a vane anemometer. We have already seen that these effects are likely to be mainly felt at low wind speeds, so that if an anemometer is employed for the measurement of such speeds, for which purpose it has an eminent superiority over other types of air-speed measuring instruments, errors may arise on account of the fact that when measurements are being taken the air density may differ from that existing at the time when the instrument was calibrated, for which conditions only the calibration curve is strictly valid.

The calibration curve or certificate accompanying the anemometer should, in the case of an instrument intended for low-speed work, bear a note recording the atmospheric density at the time of calibration. We shall assume also that the linear speed of the vanes v is known for each value of the wind speed V, since, although the calibration will be given in terms of revolutions per second for a series of values of V, it is a simple matter to deduce v from these figures and the gearing ratio and the dimensions of the instrument. Thus, if N is the rotational speed of the pointer at a wind speed V,

$$v = \frac{N}{C} = 2\pi r R n,$$

where R is the gear ratio of reduction between the vanes and the pointer.

The radius r (see list of symbols, p. 111) may be taken with sufficient accuracy as the radius of the centre of area of a blade from the axis of rotation.

The problem we are now considering is the determination of the effect of a variation in ρ on the value of the blade speed v. Let suffixes o refer to the conditions under which the instrument was calibrated, and suffixes 1 to the conditions under which measurements are being made, i.e. when the air density has changed from ρ_0 to ρ_1. For a given wind speed V_0, the linear blade speed v_0 can be obtained from the calibration curve when the density is ρ_0, and the resisting torque is given by

$$T_0 = K_0\phi_0\rho_0 A(V_0^2 + v_0^2)mr \cos(\theta - \phi_0 + \gamma_0),$$

and the end thrust by

$$P_0 = K_0\phi_0\rho_0 A(V_0^2 + v_0^2)m \sin(\theta - \phi_0 + \gamma_0).$$

Also, from (7)

$$T_0 = g + hP_0.$$

Now suppose the air density alters to ρ_1. At a certain value V_1 of the wind speed and a corresponding value v_1 of the blade speed, the torque T_1 will be the same as before.
That is,

$$T_0 = g + hP_0 = T_1 = g + hP_1,$$

from which it follows that

$$P_0 = P_1.$$

Hence

$$K_0\phi_0\rho_0A(V_0^2 + v_0^2)mr \cos(\theta - \phi_0 + \gamma_0) = K_1\phi_1\rho_1A(V_1^2 + v_1^2)mr \cos(\theta - \phi_1 + \gamma_1) \quad . \quad . \quad (9)$$

and

$$K_0\phi_0\rho_0A(V_0^2 + v_0^2)m \sin(\theta - \phi_0 + \gamma_0) = K_1\phi_1\rho_1A(V_1^2 + v_1^2)m \sin(\theta - \phi_1 + \gamma_1). \quad . \quad . \quad (10)$$

Dividing (10) by (9), we obtain

$$\tan(\theta - \phi_0 + \gamma_0) = \tan(\theta - \phi_1 + \gamma_1),$$

so that

$$\phi_0 - \gamma_0 = \phi_1 - \gamma_1. \quad . \quad . \quad . \quad (11)$$

Now γ is a definite function of ϕ, so that (11) can only be true if $\phi_0 = \phi_1$, and since

$$\frac{v_0}{V_0} = \tan(\theta - \phi_0),$$

and

$$\frac{v_1}{V_1} = \tan(\theta - \phi_1),$$

the equality of ϕ_0 and ϕ_1 leads to the relation

$$\frac{v_0}{V_0} = \frac{v_1}{V_1}. \quad . \quad . \quad . \quad . \quad (12)$$

Also, since K is a function of ϕ, $K_0 = K_1$. Hence equation (9) reduces to

$$\rho_0(V_0^2 + v_0^2) = \rho_1(V_1^2 + v_1^2),$$

and, putting in the condition represented by (12), it is easy to see that

$$\frac{v_1}{v_0} = \frac{V_1}{V_0} = \sqrt{\frac{\rho_0}{\rho_1}}. \quad . \quad . \quad . \quad (13)$$

This equation indicates a ready means of deriving the calibration curve of the anemometer at density ρ_1 from that given at

density ρ_0, since the interpretation of (14) is that a point (v_0, V_0) on the ρ_0 curve becomes the point $\left(v_0\sqrt{\frac{\rho_0}{\rho_1}}, V_0\sqrt{\frac{\rho_0}{\rho_1}}\right)$ on the ρ_1 curve. Hence a point P′ on the new curve can be obtained from any point P on the original curve, by joining P to the origin O and producing the line OP to P′, so that $\frac{OP'}{OP} = \sqrt{\frac{\rho_0}{\rho_1}}$ (see Fig. 42).

Except at the lowest speeds, the original calibration curve will generally be a straight line whose equation may be expressed in the form

$$v = pV + q, \qquad . \qquad . \qquad . \qquad (15)$$

where p and q are constants.

It is easy then to show that the corresponding portion of the calibration curve for density ρ_1 will be a parallel straight line whose equation will be

$$v = pV + q\sqrt{\frac{\rho_0}{\rho_1}}. \qquad . \qquad . \qquad (16)$$

Hence the linear portion of the new curve can be derived from that of the original curve by obtaining one point in the manner indicated above and drawing a parallel line through this point.

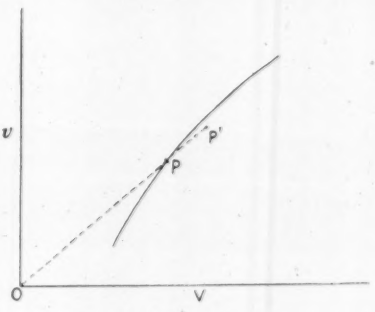


FIG. 42.

Generally, the calibration curve will not be expressed in terms of v, the linear blade speed, but of N, the rotational speed of the pointer. This will not, however, invalidate the above argument; its only effect will be to alter the values of the constants p and q in (15) and (16)

In practice it is not necessary always to draw a new calibration curve each time the value of the density changes. The air speed corresponding to an observed rotational speed can be obtained by calculation as follows. The calibration curve, obtained at density ρ_0, will be given in terms of the true wind speed V and an observed quantity, which we may denote by X, which will be the rotational speed of the pointer, or the "indicated air speed" if the dial is graduated in feet. In the latter case, X will simply bear a constant ratio to the rotational speed, so that the two cases are in effect identical. Suppose now that the quantity X is observed when the density is ρ_1.

The corresponding value of X when the density is ρ_0 will be $X\sqrt{\frac{\rho_1}{\rho_0}}$, and this will correspond to a value V of the wind speed, as determined from the calibration curve. The value of the wind speed required can then be shown to be equal to $V\sqrt{\frac{\rho_0}{\rho_1}}$. To summarise, therefore, the procedure is to multiply the observed value of X by $\sqrt{\frac{\rho_1}{\rho_0}}$; to read off the value of V corresponding to this from the calibration curve; and finally to multiply this value of V by $\sqrt{\frac{\rho_0}{\rho_1}}$.

It will generally be found that density corrections may be neglected unless the density changes are of the order of at least 5 or 6 per cent., except possibly for accurate work at very low speeds. Density changes of this magnitude rarely occur under ordinary conditions, but may easily be experienced if the anemometer is used under conditions of climate and altitude differing appreciably from those under which the calibration was made, or if the instrument is used to measure the flow of hot air.

The above methods of correction for density changes have been derived on the assumption that the friction torque can be expressed in the linear form of equation (7). This is probably not quite true at the lowest speeds, but the method of correction will be found even in this region to give sufficiently close approximations to actual conditions.

Optimum Blade Angle.—We may now consider another aspect of the relation between the frictional and aerodynamic forces acting on the vanes of an anemometer. When the wind speed is such that the vanes are on the point of commencing to rotate, the angle ϕ will become equal to the blade angle θ, and v will be zero. Hence equations (4) and (8) become

$$T = K\theta\rho AV^2mr\cos\gamma,$$

and

$$P = K\theta\rho AV^2m\sin\gamma,$$

so that, writing T in the form of equation (7),

$$K\theta\rho AV^2mr\cos\gamma = g + hK\theta\rho AV^2m\sin\gamma,$$

or

$$\rho AmV^2(K\theta r\cos\gamma - hK\theta\sin\gamma) = g. \quad . \quad . \quad (17)$$

We may use this equation to determine theoretically the angle at which the vanes of an anemometer must be set in order that they may commence to rotate at as low a speed as possible. For, since g is constant, the left-hand side of (17) is constant,

and if V is to be a minimum it follows that $K\theta(r \cos \gamma - h \sin \gamma)$ must be a maximum.

A complication is introduced by the fact that the departure from linearity of the curve of Fig. 41 at low speeds shows that h cannot be taken as the slope of the linear portion when we are considering, as is the case at present, conditions in the neighbourhood of zero rotational speed. The variation from the straight line law of equation (7) between friction torque and end thrust at very low rates of rotation may be due to a change of the coefficient of friction μ in this region. Little is known about the coefficients of friction between solid surfaces moving at very low relative speeds, but there seems to be some evidence, slight though it is, that the value of μ between surfaces at rest may be different from that when the surfaces are moving relatively to one another. Further, for all except very slow relative motions μ is found to be approximately constant, and independent of the speed. It is, then, possible that in the transition stage from rest to motion μ changes rapidly but continuously from its constant static value to its constant dynamic value. If this is so, when the vanes are just commencing to rotate, μ is probably not the same as it is when they are in steady motion, and this will furnish one possible cause for the deviation of the low-speed points in Fig. 41 from the line through the other points. Other causes that may conceivably contribute to this departure are variations in the type of flow of the air past the blades that may occur at very low wind speeds, and the interference between the blades that may tend to become more pronounced as the rotational speed becomes smaller in relation to the wind speed, that is, as the effective incidence ϕ of the blades becomes larger.

Whilst, therefore, any application of equation (17) to determine the optimum blade angle cannot, in the present state of knowledge, be regarded as rigorous, some useful indications are nevertheless supplied. If we attribute the variation in the straight line law between T and P at low wind speeds entirely to changes in μ, we may proceed as follows. Let us write μ_{max} for the constant value of μ at the higher speeds, and μ_{min} for its value when the vanes are just commencing to rotate. Since μ is no longer to be taken as constant, equation (6) must now be written in the form,

$$T = \mu(g' + h'P), \quad . \quad . \quad . \quad (18)$$

where g' and h' are constants.

If T_{min} and P_{min} are the values of T and P when the vanes are just on the point of commencing to rotate, equation (18) becomes

$$T_{min} = \mu_{min}(g' + h'P_{min}), \qquad (19)$$

and, at the higher speeds, we have

$$T = \mu_{max}(g' + h'P),$$

where $g'\mu_{max} = g$ in equation (7),

and $h'\mu_{max} = h$ in equation (7).

From (19) $$\mu_{min} = \frac{T_{min}}{g' + h'P_{min}},$$

so that $$h'\mu_{min} = \frac{h'T_{min}}{g' + h'P_{min}}.$$

Multiplying and dividing by μ_{max}, we have, therefore,

$$h'\mu_{min} = \frac{h'\mu_{max}T_{min}}{g'\mu_{max} + h'\mu_{max}P_{min}}. \qquad (20)$$

Now $h'\mu_{max}$ and $g'\mu_{max}$ are, as we have seen, equal to h and g respectively in equation (7), that is, they can be obtained by plotting T against P as shown in Fig. 41. Also T_{min} and P_{min} are the values of the torque and end thrust when the vanes are just commencing to rotate, and can be calculated by putting, in equations (4) and (8), $\phi = 0$ and $v = 0$, and reading off the value of V at which the calibration curve between v and V cuts the V-axis. Hence $h'\mu_{min}$ can be calculated by the use of (20)

Returning now to equation (17), we see that for the best blade angle $K\theta(r \cos \gamma - h'\mu_{min} \sin \gamma)$ must be a maximum, the quantity $h'\mu_{min}$ being equal to the value of h when the vanes are on the point of rotating. At this value of the rotational speed, namely, zero, the angle of incidence of the blades to the wind is given by θ, their geometrical incidence, so that K and γ can be obtained directly for a given value of θ from the data of Figs. 36 and 37. The quantity

$$K\theta(r \cos \gamma - h'\mu_{min} \sin \gamma)$$

can thus be evaluated for different assumed values of θ, and will be found to exhibit a maximum value for a definite value of θ. This angle will therefore be the angle at which the vanes should be set in order that they may rotate at the lowest possible speed.

For the author's low-speed anemometer we have already seen that $h'\mu_{max} = h = 8{\cdot}0 \times 10^{-2}$ and $g'\mu_{max} = g = 1{\cdot}6 \times 10^{-6}$. Also, from Table VIII., $T_{min} = 2{\cdot}46 \times 10^{-6}$ and $P_{min} = 2{\cdot}17 \times 10^{-5}$. Hence, from (20), $h'\mu_{min}$ will be found to be equal to 0·059. For this instrument, also, $r = 0{\cdot}115$ feet, so that the best blade angle for this type of anemometer is that at which

$$K\theta(0{\cdot}115 \cos\gamma - 0{\cdot}059 \sin\gamma)$$

is a maximum. In Fig. 43 this quantity is plotted against θ, and it will be seen that the maximum value occurs at $\theta = 31°$, which is therefore the best blade angle as indicated by the theory.

Actually, from experiments made by the author, the best blade angle for an anemometer appears to be about 40°. In these experiments, a series of tests of the minimum wind speed at which the vanes would rotate was made with an instrument whose vanes were successively adjusted to each of a number of angles of incidence. In view of the remarks made above on the uncertainty regarding the variation of frictional and interference effects that exists at these very low speeds, the discrepancy of about 9° between the theoretical and experimental optimum values of θ is not regarded as excessive.

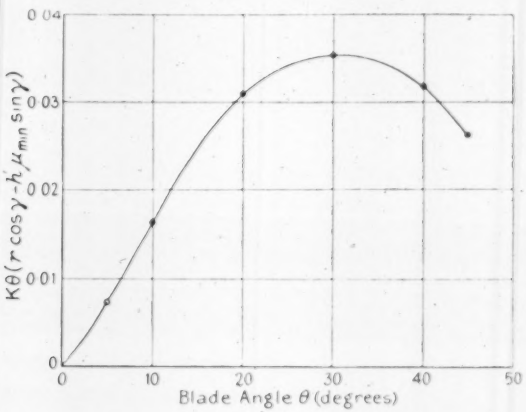


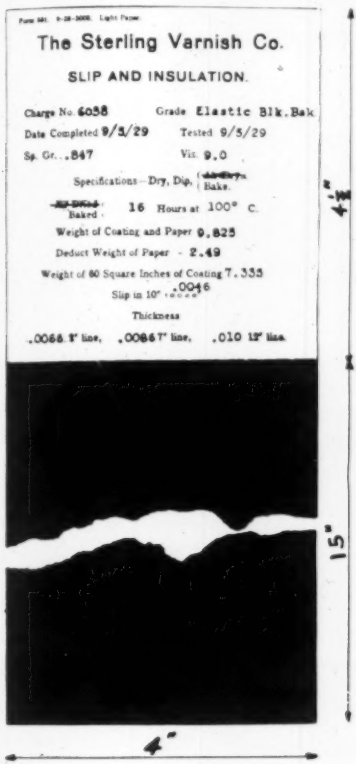
FIG. 43.

The instrument on which the tests were made was fairly representative of vane anemometers in general, and it may be taken that in all such instruments the blades should be set at 40°. The author's low-speed anemometer was designed before the theory was developed, and its blade angle of 45° was fixed arbitrarily. A similar instrument subsequently constructed with a 40° vane angle was found to commence rotation at a wind speed definitely lower than that at which motion of the original anemometer commenced.

Working Viscosity*

H. L. Hazeltine

IN the article on Viscosity Measurement of Paints and Varnishes published in a preceding number of *Instruments*, the reader was cautioned that this test should be used only to indicate the constancy of different shipments of the same material. While it is important that a paint or varnish should have as near the same viscosity as possible at all times, yet it is just as important from the standpoint of selecting materials that some means should be provided whereby the flowing characteristics of different products can be compared. In designing such a test however, careful consideration should be given to the method by which the material is to be applied so that the results may be readily interpretable in terms of the work to be done. In the case of coatings that are to be applied by the flow method—where the piece to be treated is immersed in the liquid and upon withdrawal the excess flows back into the tank or the reverse where the part to be treated is held stationary and the coating flows across the surface—the draining or flowing characteristic becomes of great importance.



In shops where this process is usually used speed of production is generally vital. Hence in order to reduce the number of applications to a minimum it is desirable that the material shall deposit a film of maximum thickness consistent with even distribution. As has already been stated, this depends upon several variables such as viscosity, specific gravity, percentage of base, etc., the exact relation between which cannot be definitely established.

The following test was devised in the laboratories of The Sterling Varnish Company for use in connection with insulating varnishes. It has in recent years received considerable recognition by various testing organizations among them the American Society for Testing Materials which has included it in its Tentative Specification D-115-29-T. It is interesting for other types of materials aside from insulating varnishes.

It has its basis upon the fact that when an article is dipped in a liquid, the liquid tends to run off thin at the top and to accumulate into a thicker

*This is the fifth of a series of articles by H. L. Hazeltine, Engineer of Insulation for The Sterling Varnish Company, Haysville (suburb of Pittsburgh) Penna.

coat at the bottom. This difference in thickness is generally called the "slip."

Test sheets are first prepared from bond paper 18″ long by 4″ wide by 2½ mils thick. A line is drawn across the paper ½″ from the bottom for the "trimming line." Three inches above this another line is drawn marked the "12″ line." Five inches higher another line is drawn marked the "7″ line" and five inches above this another line marked the "2″ line." Two inches above this still another line is drawn and called the "dipping line." Observe that it is exactly ten inches from the 2″ line to the 12″ line which distance is divided in the middle by the 7″ line.

Test papers thus prepared are dipped in the liquid at the consistency supplied up to the dipping line and withdrawn vertically at a slow uniform rate of speed. Care should be taken that the liquid is free from air bubbles. After draining thoroughly the specimens are then allowed to dry in air at room temperature in case of an air-drying material or in a baking oven, if a baking product is being used. Measurements of thickness are then taken by means of micrometer calipers at the 2″, 7″ and 12″ lines, no allowance being made for thickness of paper. The difference between the thickness at the 2″ and 12″ lines will be the "slip of the non-volatile in 10″" or as we have called it the "working viscosity." The less the difference between these measurements, the more uniform will be the deposit in actual production where pieces are treated by the flow method. The thickness at the three different points can be used as a basis of comparison with other materials to indicate the comparative thickness of film that will be deposited.

An examination of the surface of the sheets will show whether the flow of the coating has been satisfactory. There should be no wrinkles or thick spots of any kind. The sheets of paper after treatment should be perfectly smooth and level throughout with no wrinkles and no thickening noticeable at any point other than the wedgelike increase due to the slip and this slip should run uniform throughout the tests made.

R. P. Kenney has been appointed sales manager of Jas. P. Marsh & Company in the Pittsburgh district, it is announced by A. D. Rose, general sales manager, Chicago. Mr. Kenney's headquarters will be at 1120 Empire Building, Pittsburgh, Pa. The Marsh company, which is a division of the Commercial Instrument Corporation, manufactures heating systems and units, industrial instruments, automatic air valves and gages.

Ford owners doubtless will welcome a combination oil and heat indicator gage that fits and matches the new panel perfectly, which recently has been introduced to the trade by the Tiffany Division of the Connecticut Telephone & Electric Corporation.

The two instruments function separately and keep the driver informed at all times of (1) variation in the temperature of the engine and (2) incorrect conditions due to a clogged oil line, excessive dilution, inefficiency of the oil circulating system, or loss of oil.

NEW INSTRUMENTS

Recently Developed by Instrument Manufacturers

Write Information Section, Instruments Publishing Co., Pittsburgh, Pa., for additional Information.

New Output Meter

(Weston Electrical Inst. Corp.)

THE Model 571 Output Meter is a rugged portable instrument that is especially useful in checking radio sets, sound projection equipment and public address systems during both manufacture and servicing.

A few typical examples of its uses are as follows:

To measure voltage output and compute power output of radio set.

To determine the maximum gain when lining up R. F. and I. F. stages of radio sets.

To compare the gain of radio tubes.

To determine gain when a calibrated input voltage is applied to radio set or audio amplifier.

To measure comparative selectivity of R. F. tuners.

To observe period and percent of fading.

To set or keep volume of sound projection equipment at an approximately constant value.

The equipment of the Model 571 Output meter consists of a five range copper oxide rectifier type voltmeter enclosed in a sturdy Bakelite case. The ranges, 150, 60, 15, 6 and 1.5 volts, are brought out to two binding posts through a dial range-selector switch which is mounted on the front of the instrument.

The Model 571 has a non-inductive impedance of 4000 ohms for all ranges, this value being used to conform with N. E. M. A. specifications. The instrument can be connected directly in place of a magnetic (cone type) speaker or of a dynamic speaker having a self-contained transformer. If, however, the instrument is to be substituted for the voice coil of a dynamic speaker it must be shunted by a resistance approximating that of the voice coil. If the speaker is left in the circuit the meter may be connected directly across the voice coil or across the primary of the transformer.

Since the impedance of the instrument is constant for all ranges and the output voltage is measured directly it is easy to compute the power output of the radio set and adjustments can be made on the set to give the highest operating efficiency.

Size: $5\frac{1}{2}$ x $3\frac{5}{8}$ x $2\frac{1}{8}$ in.; scale length: 2.36 in.; approximate weight: 1 pound 10 oz.; ranges 150/60/15/6/1.5 volts.

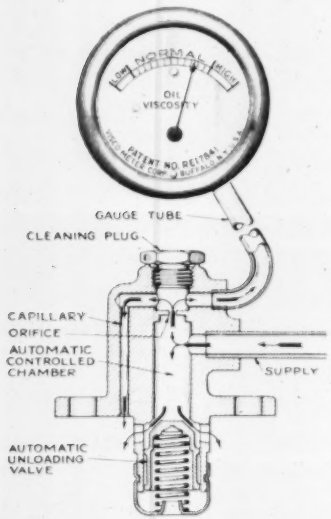
Visco-Meter

(Visco-Meter Corporation)

THE doubtful method of checking motor lubrication by means of oil pressure and oil level gages, and speedometer readings, is successfully replaced by Visco-Meter. This device is substantially built and installed on the side of the crankcase, with a gage mounted on the instrument board in full view of the driver. Visco-Meter is not a pressure gage, nor an

amount indicator. Its function is to measure and indicate viscosity (body) of the motor oil continuously while the motor is running.

The design and operation of the Visco-Meter device is very simple. It is connected with the oil pressure line where working pressures exceed 8 lbs./in.². An automatic unloading valve reduces a small portion of oil to a constant 5 lbs. pressure in the chamber. The oil then passes through the calibrated orifice into a divided chamber. One branch is connected with a calibrated capillary resistance tube; the opposite branch is connected with the registering gage, usually placed on the instrument board.



Light-bodied oil passes through the capillary tube freely, with little resistance. Thus, there being but slight back-pressure on the registering gage, it indicates low viscosity. When the oil is more viscous it does not pass through the tube so easily: the capillary offers more resistance. This sets up a back-pressure on the registering gage, and it indicates greater viscosity.

Drivers and fleet owners who have used Visco-Meter equipped motors claim an appreciable saving from them. For besides definitely protecting the motor against the many lubrication disorders that cause costly repairs, Visco-Meter affords a scientific basis for changing the crankcase oil.

This device also shows up improper oils, excessive dilution from badly fitting rings, overheating of motor, oil leaks, faulty oil pumps and dangerously low pressures.

Black Back Mercury Thermometer Tubing

(Scientific Instrument Co.)

QUICK accurate temperature reading is a major requisite on all kinds of modern equipment and the development of a mercury thermometer to meet this demand is found in this black back thermometer tubing.

Thermometers are necessarily delicate instruments, made of glass, and therefore must be placed in such places that they will not be easily broken—usually on the side of a machine where the light is rather dim.

It was with this thought in mind that this black back tubing was developed as the mercury in a dimly lighted place has much the same effect on the black background as a luminous dial on a watch, in fact you can see the mercury from 15 to 20 feet away, further than you can read the figures on the scale.

The silver color of the mercury on the black background eliminates any confusion in reading, as is the case with other types of tubing using as a background a color that is the same color as a liquid used in making some types of thermometers and, further, the mercury although showing the best directly in front, can be seen at an angle of 60° either side.

This type of thermometer can be made either with lens front or round tubing as used in making laboratory chemical thermometers.

This thermometer tubing is the same as standard white back tubing in every way except the black background is substituted for the white background.

Burgess Acoustimeter

(Burgess-Parr Company)

THE Burgess acoustimeter is a recently developed instrument for the measurement of sound intensity. It may be equipped either for the measurement of air-borne sounds or of vibrations existing in structural parts.

It is of such great sensitivity that it can detect and measure accurately even those sounds whose intensity is at the threshold of audibility, and has sufficient range to measure sound intensities throughout a range of 70 decibels. Its response is practically uniform throughout a frequency range from 30 cycles to 8,000 cycles.

Fig. 1. Measuring office noises by means of a Burgess Acoustimeter. Arrow indicates microphone.

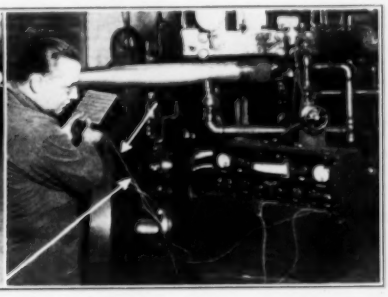


Fig. 2. Acoustimeter with No. 25 Pick-Up used to locate the source of vibrations in machinery.

The sensitivity, wide frequency range, and adaptability to the measurement of either air-borne or structurally transmitted vibrations, make the Burgess acoustimeter particularly suitable as a research instrument for acoustic studies. Among the problems to which the instrument has been applied are the measurement of noises caused by gears, pumps, motors and ventilating ducts, the silencing ability of automobile mufflers, window ventilators, etc., the preparation of city noise surveys, and the study of detonation in internal combustion engines. Other fields of utility are the study of loud speaker charactersitics, the investigation of the acuity of hearing, the determination of sound absorption coefficients, periods of reverberation, and other allied noise measurements.

The acoustimeter proper consists of a specially designed vacuum tube amplifier, a gain control whereby the amplification may be varied in steps of 5 decibels, and a sensitive indicating meter. Means are provided for calibrating the amplifier and meter system by the use of a 110 volt, 60 cycle current. The unit, with C batteries installed, weighs approximately 50 lbs., and is contained in a portable fabrikoid covered case.

The pick up used for the measurement of air-borne sounds is a Jenkins & Adair condenser microphone calibrated to the particular acoustimeter with which it is used. Sound energy entering the microphone is transformed into electrical energy and transmitted to the amplifier, where it is indicated by the meter.

The Burgess No. 25 Pick-up is a rigid coupled device operating upon a seismometric principle. It is attached firmly to a vibrating unit, such as for example the base plate of a motor. The existing vibrations are transformed into electrical energy, which is amplified by the acoustimeter circuit and indicated on the meter. An extension rod of variable length is provided so that the unit may be used to probe for vibrations in machinery.

Various types of filters to separate one group of frequencies from another, can be provided, and can be installed either as internal or external accessories.

New Standard Data

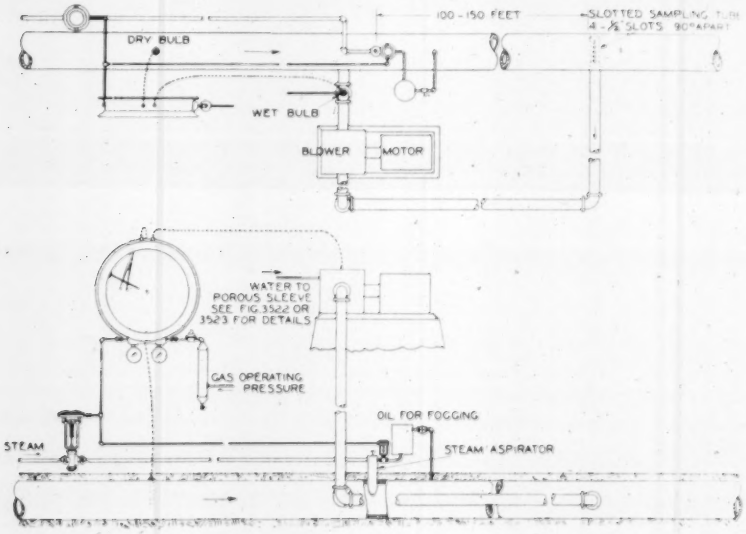
A new compilation of data entitled, *Measurement Units and Standards*, is issued by the American Institute of Weights and Measures, 33 Rector Street, New York, and a copy of this book may be obtained gratis by applying to the Institute, William E. Bullock, Secretary. In addition to the data on units and standards, the book contains an article recommending *timex* and *spacex* as names for the Einstein specialization of basic time and space. It also contains a useful description of the difference between a *unit* and a *standard*, prompted by the lack of unanimity existing in reference publications.

Saturation Controller

(*Foxboro Company*)

THIS instrument, known as the Saturation Controller, is designed to solve the problem of correctly saturating natural gas to prevent the drying out and subsequent leakage in any line formerly used for the distribution of manufactured or wet gas.

The operating principle of the saturation controller is unique and differs entirely from any other. Basically it is a wet-and dry- bulb psychrometer. Control of the saturation point is maintained by the wet-bulb thermal system which operates a controlled valve in the steam line leading to the aspirator. A hookup is possible whereby oil fogging can be accomplished through the same steam aspirator. A sample of the saturated gas is drawn from the line by a motor blower which circulates it over the wet bulb thus insuring the correct velocity for



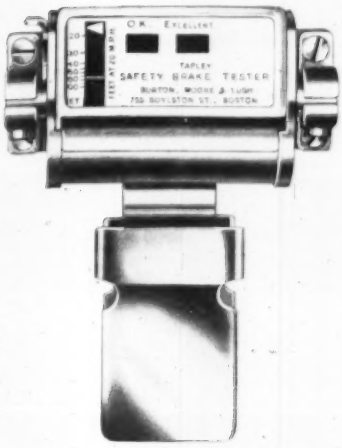
evaporation. The dry-bulb thermal system operates a power diaphragm inside the instrument which resets the saturation point to conform with changes in temperature in the line. This means that changes in the gas line temperature will constantly reset the saturation point so that the gas will always be saturated at the gas line temperature. This is a very important point for if the gas is not practically saturated it will eventually dry out the line and cause excessive leakage, and if it is saturated at a temperature higher than the line temperature it will cause condensation troubles.

The saturation controller is of the air-operated type. On this particular service, however, air is unnecessary since the controller can be operated directly from the gas pressure in the line if that pressure is 2 lbs. or over.

New Tapley Safety Brake Meter

(*Burton-Moore & Lush*)

THE Tapley Brake Meter is an accurate instrument to aid the public safety movement for better brakes. Produced by arrangement with the manufacturers of the larger Tapley Brake Testing Meter used in the United States and Canada by police officials, registrars of motor vehicles and car manufacturers, this smaller instrument represents an engineering



achievement, remarkable for its permanent accuracy, ease of use, and small size.

The movement is governed by a small phosphor-bronze ball inclosed in a pivoted inclined tube. When the brakes are applied, the stored-up energy of the ball due to the motion of the car, is released and it rolls up the inclined tube passing the pivot, tilting the tube and holding it in its registering position.

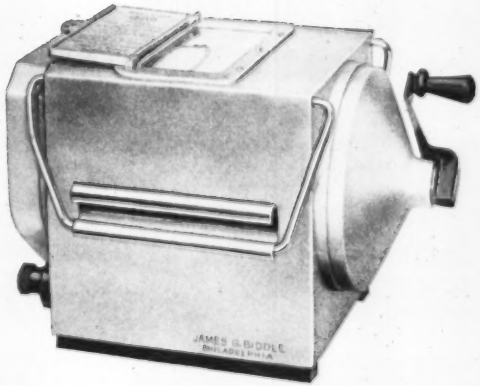
It is easily and quickly applied to the dash of any car by means of a specially constructed snap clamp attached to the back. The pointer at the left is first adjusted to coincide with the stopping distance in feet desired as the basis for test, while the car is standing on level ground or garage floor.

The orange colored indicator marked "O.K." is attached to the bottom of the tilting tube and will appear in the first or left window of the instrument only when sufficient braking power has been applied to the car to stop it in the distance equal to the original setting of the pointer.

A second tube with a green indicator attached to its bottom is also provided, and this is so arranged that it will appear in the second window at the right when the braking power applied to the car is approximately 8% more than the pointer setting.

1000-Volt "Super-meg"

(James G. Biddle Co.)



THIS is a light weight compact and relatively inexpensive instrument for testing insulation resistance up to 200 megohms at 1000 volts. It is especially intended for use by power companies, street railways, steam and electric railroads, and industrial plants for testing practically all types of 440 and 600-volt equipment at a potential that is definitely higher than the working voltage. Also it is suitable for testing motors, generators and cables of higher voltage ratings where readings of insulation resistance do not normally run over 200 megohms. On 220, 110 and lower-voltage apparatus it conveniently provides a combined insulation resistance and high potential test.

For testing transformers, bushings, insulators, etc. and high-tension equipment having insulation resistance higher than 200 megohms, our 1000-volt "Megger" Testing Sets continue to be recommended, because they have the necessary ranges up to 5000 megohms.

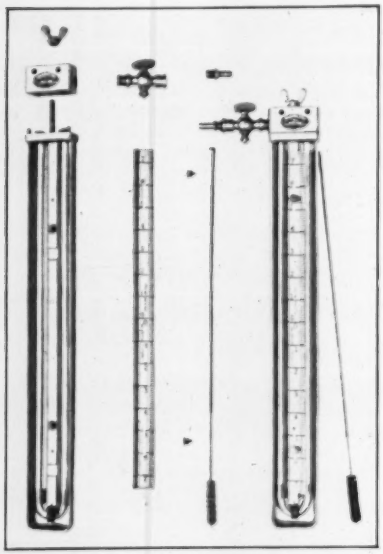
The drive mechanism has the "slip clutch" device by which a constant voltage is generated for the test so that large apparatus and long cables with considerable electrostatic capacity can be tested, and steady, accurate readings obtained. The indicating portion of the instrument is a true ohmmeter—unaffected by the exact value of the voltage applied for the test.

To use the instrument simply make connections, turn the crank at about 160 r.p.m. until the clutch is felt to slip—and read the scale.

New Design U-Tube Manometer

(Meriam Co.)

THE instrument consists of 2 separable parts—the head, which is permanently attached by the pipe connectors to the line; and the housing which carries the scale and tube, and which may be readily removed from the head by unscrewing a convenient wing nut.



The top of the housing carries a threaded column which passes completely through the head-casting and serves to carry the wing nut.

The wing nut engages with a vertical stud in the housing, and serves to hold the 2 parts of the instrument in place. The rubber gaskets which keep the ends of the U-tubes pressure-tight fit into tapered holes in the head communicating with the pipe-line, and thus a moderate tension of the wing nut exerts ample compressive force on the gaskets to prevent all leakage. Dowel pins assure correct alignment of the head and housing. Spring clips at the back of the housing hold a cleaning brush suitable for the size of U-tube used.

The new instruments are expected to be a great convenience in the many cases where dirt is carried over from the pipe line into the instrument; or where for any reason it is desired to replace a broken tube, or to replace one instrument by another of different capacity.

These conveniences are obtained without in any way sacrificing the basic andpermanent accuracy of the regular U- tube type of manometer or flow meter. The instruments are designed to withstand all line pressures up to 100 lbs./in.^{2}, and may be supplied to measure any differential pressures up to approximately 50 lbs./in.^{2}—or flows giving an equivalent differential.

Magnetic Strain Gage

AT the annual meeting of the American Society of Civil Engineers, Brian Wheeler demonstrated a magnetic strain gage, in the course of development by the Westinghouse Electric and Manufacturing Company.

While the small contrivance has a very prosaic appearance and gives no hint of its unlimited value, it can reduce the element of danger in all kinds of travel, it can help engineers and architects to design structures more skillfully and with a greater factor of safety, and it is capable of measuring surely and accurately stresses and strains which have had to be computed with only approximate results in the past.

Engineers see in this gage a piece of equipment that should reduce the possibility of building failures, buckling of bridge trusses and similar catastrophes. Applied to railroad rails it not only reveals the amount and location of strain but it is a device that will disclose certain faults in locomotive construction if they exist.

Mr. Wheeler demonstrated the gage attached to a small aluminum beam about 6 feet long and weighing 11 lbs. It was shown that the device is so sensitive it will record different readings when the beam is turned on its 2 flange sides and without the application of any weight other than that of the light, exhibition beam. These readings are instantaneous and visual, a feature which is regarded as a marked improvement over those types of strain gages which require mathematical calculations.

Mr. Wheeler explained how the wind pressure at any point of a modern skyscraper can be measured by bolting the gage to steel members of the structure, determining first whether that portion of the building is under stress or compression and then determining the amount of strain required to withstand the wind pressure at the moment the reading is made.

Similar knowledge can be obtained on recording meters where changes occur slowly and readings must be made over a period of weeks or even months. It can be used for micrometer measurements in the shop and it will give results of higher accuracy than those formerly obtained.

While the gage is not available on the market, tests made by Westinghouse, particularly where changes of stress were at high rates of frequency, indicate it has potential value in scores of practical applications. Stresses have been recorded at the rate of 30 per second but this figure can be increased by speeding up the movement of the film of the oscillograph on which the curves are shown.

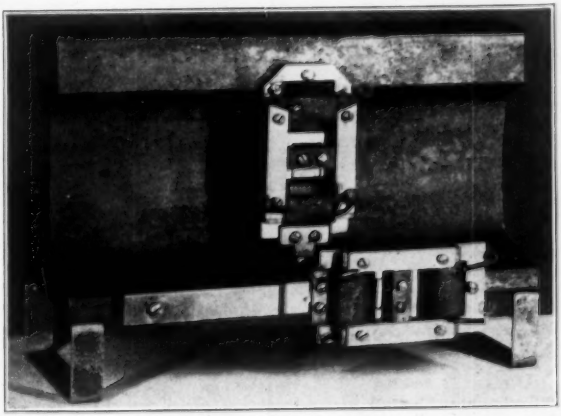
Mr. Wheeler exhibited photographs of such graphs as made on railroad rails and explained how 8 readings were made and recorded simultaneously on the head and the base, inside and outside of each rail. These curves not only indicated the passing of each wheel of a locomotive, tender and coach but illustrated the lateral forces exerted by the flanges of those wheels as well as the vertical forces of the weight.

One graph indicated plainly that a certain mountain locomotive with 5 driving wheels was too long to be safe on a curve of certain sharpness and that its length and rigid construction exerted a tendency to turn the outer rail over on its side.

Gages on the rails also disclose the lateral oscillation of locomotives by recording the impact and blow on the side of the rails. It is also adaptable for similar studies of bolts, plates and joints of railroad and it is possible that the design of a better and safer type of rail will be indicated by the series of observations possible with the new gage.

In construction, the Westinghouse gage is about 8 inches long with bolt holes in the 2 ends. The center section has 2 coils of wire which carry an electric current. A moving armature is adjustable within narrow limits and the slightest movement of this armature between the pole pieces changes the air gap across which the flux must pass from the 2 hole pieces to the ends of the armature.

Three wires carry the current through the gage and either to the recording instrument or to the oscillograph where readings can be made or photographs taken as desired. The changes in the length of the air gaps upset the balance of the voltages across the gage coils and indicate the degree of strain in the beam or rail at the point to which the gage is attached.



Method of attaching magnetic strain gages to a railroad rail so that stresses in both the head and the base of the rail can be measured simultaneously as the train passes above the point of attachment.

By measuring these fluctuations in an electric current, this simple but sensitive mechanism will help to prevent railroad wrecks, can condemn unsafe bridges or buildings. It can show engineers and architects how to build strength into structures where it is needed and it can examine materials for defects that may carry the threat of death and disaster so long as they remain undiscovered

weight other than that of the light, exhibition beam. These readings are instantaneous and visual, a feature which is regarded as a marked improvement over those types of strain gages which require mathematical calculations.

New Strain Gages

(F. F. Metzger & Son)

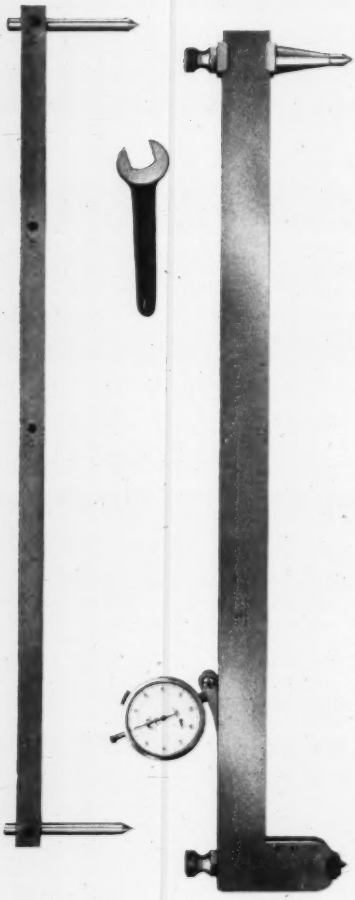


Fig. 1

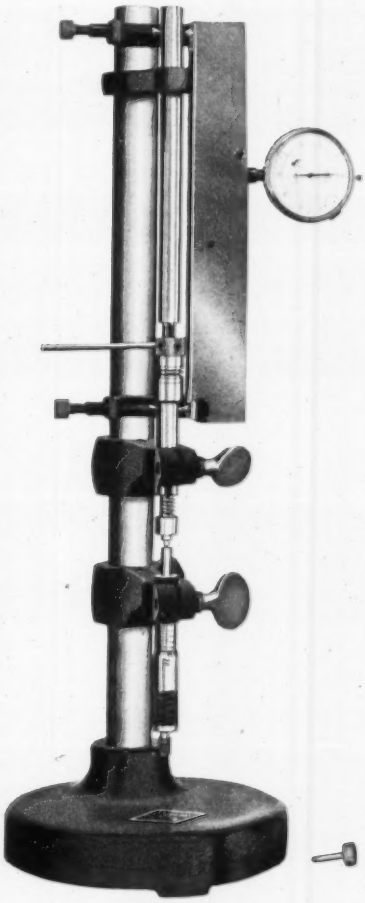


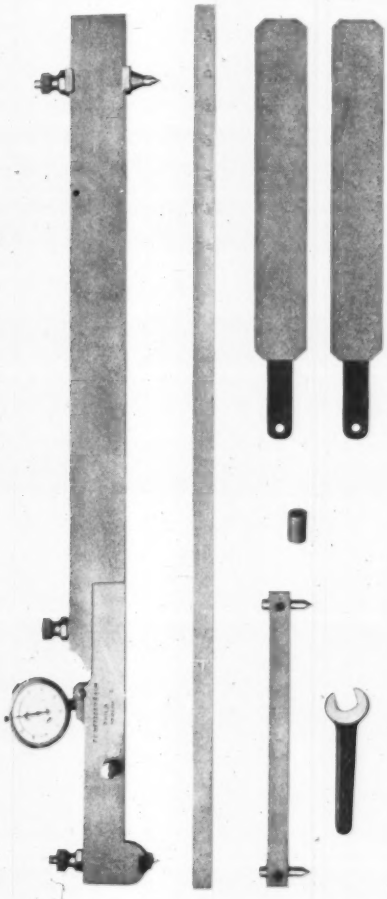
Fig. 2

Fig. 1 is an illustration of a 20″ strain gage with a clearance of 2″ under the frame to permit of taking measurements on steel in concrete, or in structural steel work. This instrument has a range from 10″ to 20″ obtained by means of clamp holding the punch, which can be set and fastened to any desired length between points. The dial micrometer reads direct to .0001″ per division with a maximum of .030″. The frame is made of 36% nickel alloy steel. The holes in the punch bar are arranged for clamping the punch for distances of 10″, 15″ or 20″ lengths.

Fig. 2 STRAIN GAGE CALIBRATOR

This illustration, with an 8″ strain gage attached, is an instrument specially designed to check any make of extensometers up to 10″ and will accurately indicate any differences of error in dial micrometer readings over the entire range. The construction consists of a shaft sliding in a sleeve, both made of tool steel, and the various spacings are accomplished by a knurled nut resting on ball bearing which permits of a sensitive movement for the various indications. This shaft and micrometer screw are clamped by brackets to the upright bar in the base. The upper bracket is not fastened to vertical bar; it is held there in slidable contact to prevent the micrometer shaft from rotating.

passes above the point of attachment.



THE basis for these strain gages is the multiplying lever. Mechanical means have proven to be the most reliable, practical and quickest method with everything in open view before the operator. Readings of instruments of this type are accepted with confidence and assurance of correctness by inspectors.

The levers are made of channel cross section for rigidity and lightness in the proportion of 1:10 with a knife edge bearing in V shape seats and held therein by a spring at the pivotal axis of the lever.

The dial micrometers will read direct to .0001" per graduation and are especially adjusted for the required accuracy. The maximum range is 0.030" in extension or liniar deformation of specimen. Dial micrometers reading to 0.00001" per graduation can be supplied. Two clamps accomodating specimens up to 1"D. are furnished to hold specimens opposite the engaging points.

Fig. 3 is an illustration of an 8" strain gage with extension to 24" and having a clearance of 1" under the frame. This gage is specially constructed for shop use on large castings to measure differences of deformation in machining. It can also be clamped to a casting by clamps provided with springs engaging the projecting pins in the knurled head screw of the instrument, and the differences of deformation are indicated during the process of machining. This instrument has a range from 9" to 24", obtained by means of a clamp holding the punch in the extension frame which can be set and fastened to any desired length between points. The standard reference bar is used for resetting the strain gage for repetition of tests. First set the dial micrometer to zero with the gage pin in frame of the 8" instrument. Place the point of the movable lever in hole marked 0 on the reference bar, then set and clamp the punch in the extension frame to the required distance between points. The dial micrometer reads to .0001" per graduation with a total limit of .030". To assemble the instrument to an 8" strain gage, remove the extension frame and point, then fasten the clamp holding the point into the end hole of the strain gage. The small collar is inserted to make up the difference in the width of the strain gage.

ALFRED SUTER 200 FIFTH AVENUE NEW YORK

Sole Representative of

THE LOSENHAUSENWERK DUSSELDORF

Manufacturers of Complete

TESTING MACHINERY EQUIPMENT

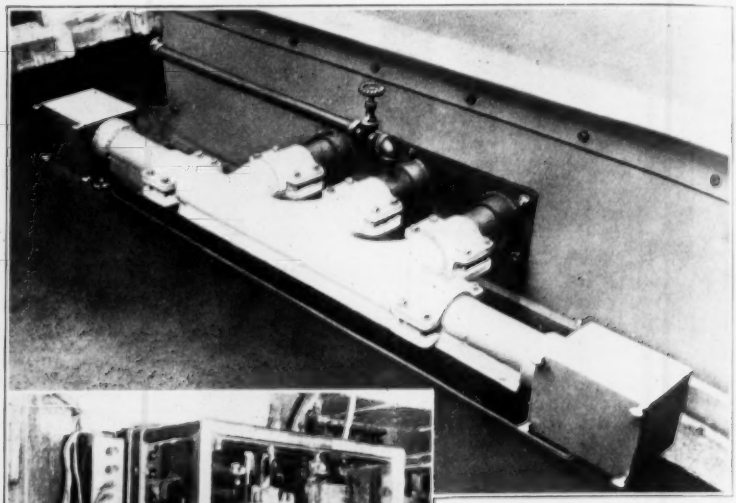
for Research and Works Laboratories

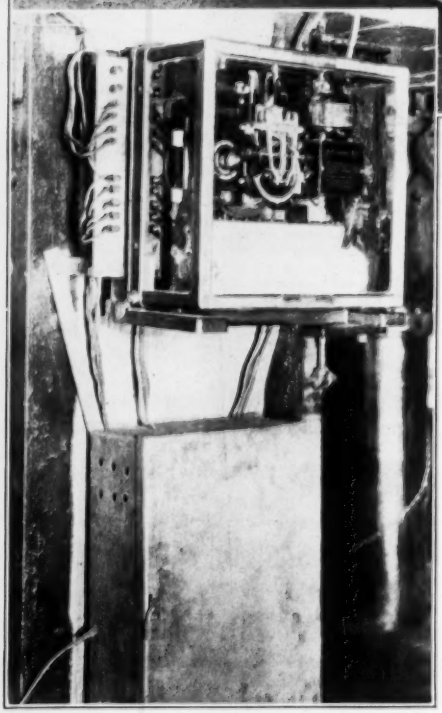
New Smoke Recorder

(Leeds & Northrup Co.)

THE smoke recorder consists of a measuring chamber at the stack or breeching, a recorder at any convenient location and an indicator at the boiler.

The measuring chamber, through which the smoke passes, contains a lamp at one end and a specially constructed, temperature compensated thermopile at the other. Heat radiated from the lamp passes through the smoke-filled chamber and falls on the thermopile. With a constant heat-source in the lamp, the amount of heat falling on the thermopile is inversely





Above An installation.
At left Recording instrument.

proportional to the density of the smoke. The heat from the lamp which reaches the thermo-pile causes it to generate a voltage. The measurement of this voltage is the measure of the smoke density.

Advantages of the smoke recorder

1. The boiler room indicator instantly tells the fireman the smoke condition.
2. The recorder furnishes a continuous record 24 hours a day.
3. The apparatus is simple, reliable and fool-proof. A specially constructed thermo-pile is used as the detecting element.
4. The density measurement is not affected by line voltage fluctuations.
5. The sampling system, of which the measuring chamber is a part, is easily installed, requires very infrequent attention, and provides a ready means for obtaining a condition of zero smoke-density for purposes of checking.

New Instrument Measures and Controls Heating Effect of Gases

A. E. Krogh*

A WIDELY useful instrument for checking the heating effect of fuel gas has been developed by the Brown Instrument Company. The new instrument, which is called the Brown Flame Analyzer, can be supplied to measure, record and automatically control the heating effect of any gas. With this instrument gas companies, industrial plants using producer gas, and the many new plants supplying butane gas to small communities, are enabled to check and regulate the quality of their gas output with special reference to heating effect. In the many cases where it is necessary to dilute a rich gas, or enrich a lean gas, the flame analyzer equipment not only makes it easy to observe and record the quality of the output, but makes possible a dependable automatic control of the mixture that will insure a uniform product. The value of such a device is self-evident in numerous industries where gas fuel is largely employed, as well as being a boon to the manufactured gas field. To the latter it will be of great assistance, providing gas of maximum utility to the consumer at minimum cost; especially since the gas analyzer is of direct assistance to the operator of the gas making machines.

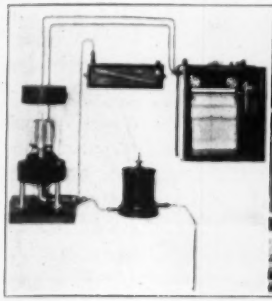


Fig. 1

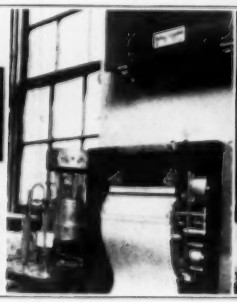


Fig. 2

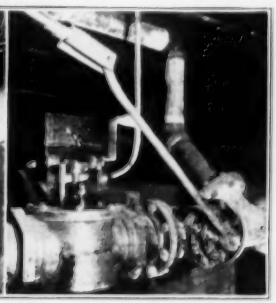


Fig. 3

However, in many industrial processes the Brown Gas Analyzer, particularly in its automatic control type, can materially aid production. There are a great number of cases in industry where the heating effectiveness of gas fuel is vital in manufacturing processes where great sensitivity to changes in the rate of heat propagation are carried on. Such an example, for instance, is a lamp factory. All lamp factories must contend with the problem of maintaining a very large number of small gas flames at uniform temperatures. These flames are used in sealing the glass bulbs. If the effective temperature of the flames suddenly changes, the work will be damaged. The Brown Flame Analyzer can be put into such a factory and, when connected to the necessary control equipment, will maintain a uniform pilot flame in the analyzer, which in turn will result in unvarying flames throughout the plant.

Fig. 1 shows the Brown Flame Analyzer, together with the recording instrument and a pressure governor and gage controlling the flow of gas through the analyzer.

Fig. 2 shows an installation at the plant of the Louisville Gas and Electric Company, Louisville, Ky. The Brown Flame Analyzer has a very broad field applying to the needs of the gas companies, the large gas consumers, the great iron and steel plants where efficient utilization of immense volumes of coke oven gas and blast furnace gas is an important problem, and to special requirements in many fields and processes where gas is used. Fig. 3 shows a gas mixing valve automatically controlled by the Brown Flame Analyzer at the Louisville Gas & Electric Company, Louisville, Ky.

*Development Engineer, The Brown Instrument Co., Philadelphia.

Van Cittert's Double Monochromators

(*P. J. Kipp & Zonen*)

Glass Double Monochromator. In order to obtain a narrow region of wavelengths, Dr. van Cittert has constructed a new type of monochromator, represented diagrammetically in Fig. 1.

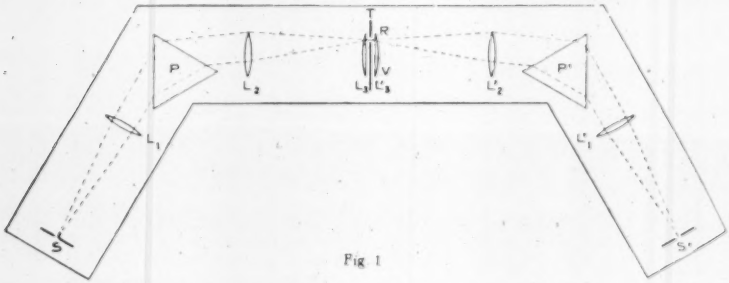


Fig. 1

An image of the source of light used is projected onto the slit S. The dotted lines show how the beam of light is converged by the lens L_1, passes through the prism P (which is at minimum deviation), and after passing lens L_2 forms a spectrum in the plane of the slit T.

The slit T, the width of which is adjustable, can be placed in various parts of the spectrum. After passing this slit, the monochromatic beam traverses the second optical system, which is identical with the first one. The beam converges onto the slit S' and emerges from there independently of the position of slit T. The two lenses L_3 and L'_3 are intended to concentrate all the rays coming from L_2 and transmitted by T on to lens L'_2.

The function of the right half of the instrument is to clear the monochromatic beam from stray light. In a single monochromator this stray light is inevitable; it is caused by reflection and scattering in the various parts of the instrument. Thus while the left half of the double monochromator gives some stray light, if this amounts to about 5%, the two halves together only give 2½ %.

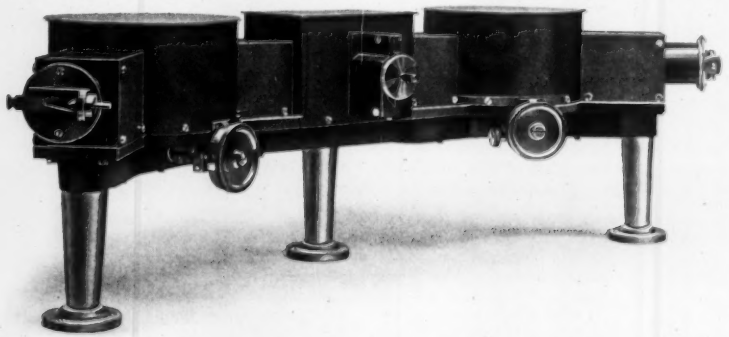


FIG. 2

*Development Engineer, The Brown Instrument Co., Philadelphia.

Fig. 2 shows the complete instrument. The principal features of this monochromator are:

1. Monochromatic light of great purity.
2. Very large aperture, about F/3, the focal length being only 100 mm.
3. Rapid adjustment to any region of wavelengths by a simple displacement of slit T, the position of which can be read off in hundredths of a millimeter. A dispersion curve is supplied with each instrument. (The narrowness of the spectral region is controlled by the width of the three slits. As a rule, these slits should have an equal width).
4. The beam emerging from the instrument always has the same direction and the same aperture.
5. The distribution of energy throughout the spectrum may be determined by direct measurement, i.e. with the thermop le. After removing the central slit, which is arranged for in a very simple way, a white beam of light, of which the distribution of energy is exactly known, will emerge. The slit S' can be considered as a source of light of which the distribution of energy is exactly known.
6. Both prisms are made of dense flint glass of refractive index $n_D = 1.717$ and dispersion $(n_F - n_C) = 0.04231$.

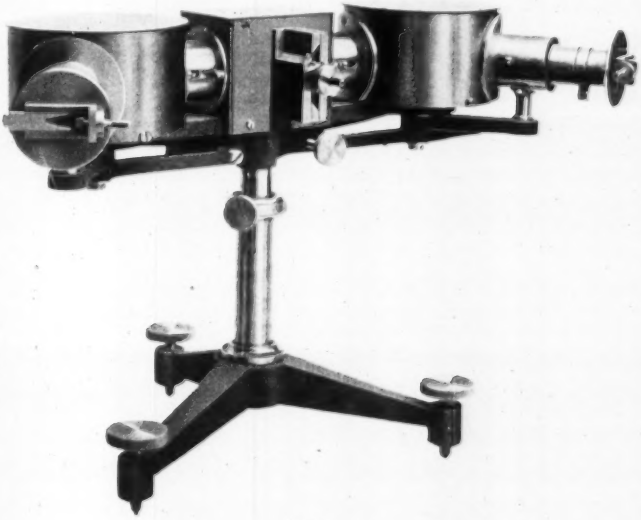


FIG. 3

A small removable prism is mounted in the instrument, in order to facilitate the sharp projection of slit S on to slit T, when re-adjustment is necessary. The lenses L_1 and L_2, as well as L'_1 and L'_2 can be displaced and their position fixed and read off, in order to allow focussing for infra-red rays up to 17000 A. U.

For the energy measurements the Moll micro-thermopile, which may be either attached to the instrument in such a way that its slit replaces the end slit of the monochromator, or placed behind this instrument, is used. In the latter case the end slit of the monochromator is projected onto the slit of the pile by means of a set of lenses. For projecting an image of the

FIG. 2

source of light onto the slit S, as well as to project the slit S' onto the thermopile, special lens systems are used. These adjustable systems, mounted on stands, are corrected for visible light, and allow full advantage to be taken of the large aperture of the instrument.

Quartz Double Monochromator. If investigations are to be made over a wider range of wavelengths than that possible with the Glass Monochromator (4000—17000 A. U.), Dr. van Cittert's Quartz Double Monochromator can be used from 2000—27000 A. U.

The principle of the instrument is the same as that of the Monochromator described above.

As it is impossible to correct quartz lenses for achromatism over a wide region of the spectrum, special focussing mounts have been provided.

Both sides of the instrument being identical in optical construction, each pair of lenses has its own focussing collar and by rotating this, the lenses of each pair move together and by exactly similar amounts.

The focussing collars are provided with divisions and an index mark, and with the help of the dispersion curve supplied, the wavelength can be accurately determined, and the position of the lenses set accordingly.

The aperture of the instrument is about F/4 with a focal length of 140 mm, and this length can be varied between 120-160 mm.

The position of slit T can be read off from a divided scale 40 mm in length in hundredths of a mm; a dispersion curve gives the position of this slit in the spectrum. As slit S is projected as a curved line in the plane of slit T, the jaws of the latter are not straight, but curved.

Nephelo- and Absorptiometers For White and Monochromatic Light

(P. J. Kipp & Zonen)

Nephelo and Absorptiometer for white light. This instrument, formerly described by Prof. Dr. W. J. H. Moll of the Physical Laboratory, University of Utrecht (Holland), under the name of "Extinctiometer," has been designed for the measurement of turbidity and absorption.

Contrary to the well-known visual methods, the measurements with this instrument are absolutely objective.

The principle is very simple. A source of light (a small 4 volt ½ watt incandescent lamp of 25 C. P.) is fixed between two thermopiles I and II. Shunts of equal resistance (50 ohms) are connected in parallel with the thermopiles, one of them being subdivided into 9×5 ohms $+ 10 \times 0.5$ ohm. These shunts are connected to a galvanometer as shown in Fig. 1.

The instrument has to be so adjusted that the radiation from the lamp excites electro-motive forces in the thermopiles, giving equal currents in the shunts. Small differences may be compensated by means of the carbon rheostat. (Fig. 1.)

If the turbidity or absorption in the two glass vessels, placed between the thermopiles and the lamp, is the same, the galvanometer will remain at zero. If, however, the turbidity or absorption in the vessel between the lamp and thermopile I is greater than that in the other vessel, the radiation

received by thermopile I is less and the galvanometer will show a deflection which is brought to zero by means of the divided shunt connected with thermopile II. This shunt acts as a potentiometer.

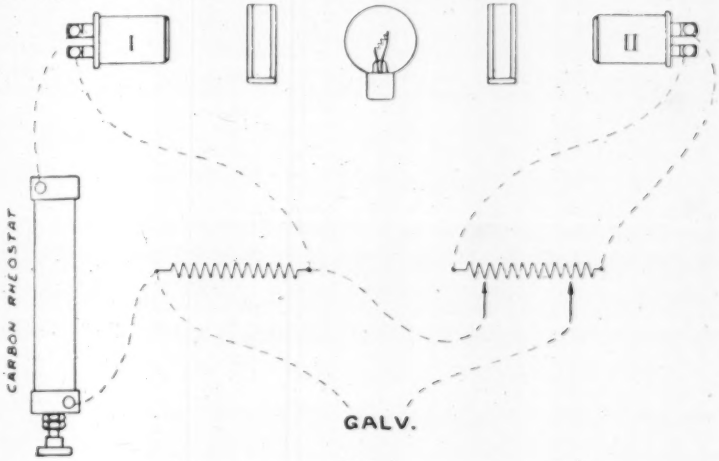


Fig. 1

The reading of this divided shunt immediately gives the turbidity or absorption as a percentage of that in the other vessel.

The efficiency of this method depends entirely on the quality of the thermopiles which are of the Moll pattern. They are to a high degree free from error, are rapid and very sensitive.

The construction will be evident from Fig. 2. Upon a wooden base an iron rail of triangular cross-section is fixed, along which 5 saddles may be moved. The outer ones carry the two thermopiles and the middle one a lamp with condensers. On the remaining carriers two holders for glass vessels are placed, which also allow the attachment of an extra small vessel of $4 \times 4 \times 1$ cm, which can be used as a liquid filter in such cases, where a more monochromatic light is required; i.e., if absorption in the visible region has to be measured, it is preferable to eliminate the infrared radiation by means of a solution of 3% $CuCl_2$.

The thermopiles are connected to terminals, to which the switchbox containing the nondivided as well as the subdivided shunt, is connected.

Sensitivity. If the vessels are filled with water and the turbidity in the vessel in front of thermopile I is 1 % more than that in the other vessel, the Moll galvanometer gives a deflection of 10 mm on a scale at a distance of 30 cms, so that a turbidity of 0.1 % can easily be measured.

Nephelo- and Absorptiometer for monochromatic light. The principle of this instrument, is exactly the same as that of the nephelometer for white light descrided above.

Instead of the lamp (See Fig. 1) an adjustable slit with two reflecting prisms behind it is mounted on a yoke, movable on the triangular rail. This slit is illuminated by a monochromator of great light intensity, placed on the same heavy cast iron base and at right angles to the rail .

The source of light consists of a 3 volt, 2 amp. incandescent lamp with a tungsten filament, which at the same time serves as the primary slit. The

optical system of the monochromator consists of an achromatic condensing lens system forming a parallel beam of light, which passes through a large Amici triple prism, while a second achromatic lens projects the spectrum onto the adjustable slit mentioned above.

The light passing through this slit is reflected by the reflecting prisms, one half to the left, the other half to the right. Each of these beams of light is made parallel by an achromatic lens, passes through a glass cell and is afterwards condensed by an achromatic lens system onto the thermocouple.

In order to project any part of the spectrum onto the adjustable slit, the lantern is mounted on a rising and lowering stand, adjustable in height by means of a screw and a rotating collar. The center pillar and collar are divided and the position can easily be read off. A dispersion curve is supplied with the instrument, so that any desired part of the spectrum can be projected onto the slit.

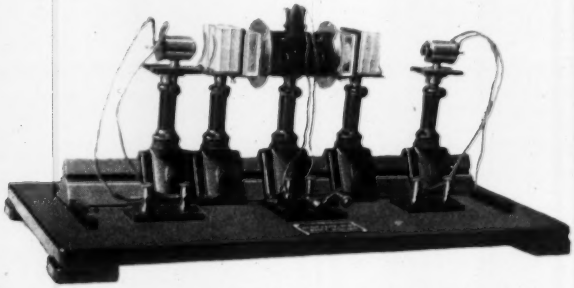


Fig. 2

Thermopiles, as used in the nephelo- and absorptiometer for white light, would not be sensitive enough for this instrument, as only a small part of the total light energy falls on the junction. Therefore vacuum thermocouples of the highest sensitivity are used. A magnifier, fitted behind the couple, enables it to be accurately adjusted in the beam of light. Vertical as well as horizontal movements are provided. The same shunts as those for the nephelometer for white lights are used.

The glass cells are of cylindrical form, with plane glass windows (diameter 50 mm, width 30 mm). They are provided with a device for filling, so that the liquid enters at the bottom, thus avoiding air bubbles. The liquid is let out by a stop cock, while a second tube, entering at the top, allows the cell to be cleaned very quickly while always remaining in place, a point which is of great importance for accurate investigations.

On the heavy cast iron base, terminals are mounted to connect the vacuum-thermocouples, the switch-box containing the shunts, the lamp and its storage battery. A resistance, switch and small voltmeter for controlling the voltage of the lamp are also mounted on the base.

Sensitivity. In the green part of the spectrum between 5250 and 5350 A. U. with a slit of ¼ mm width (100 A. U.) and the lamp burning at 3.2 volt, the deflection of the type Zc galvanometer is 5 mm on a scale at 1 meter distance for 1% absorption, both cells filled with water, so that 0.1 % may easily be observed. Under the same conditions, in the violet between 4050 and 4150 A. U. with a slit of 0.8 mm width (100 A. U.) the deflection of the galvanometer is 2½ mm on a scale at 1 meter distance for 1% absorption.

The Amici-prism can easily be moved out of the beam of light, thus permitting the instrument to be used with white light. Of course, the sensitivity is then enormous and great care should be taken to safeguard

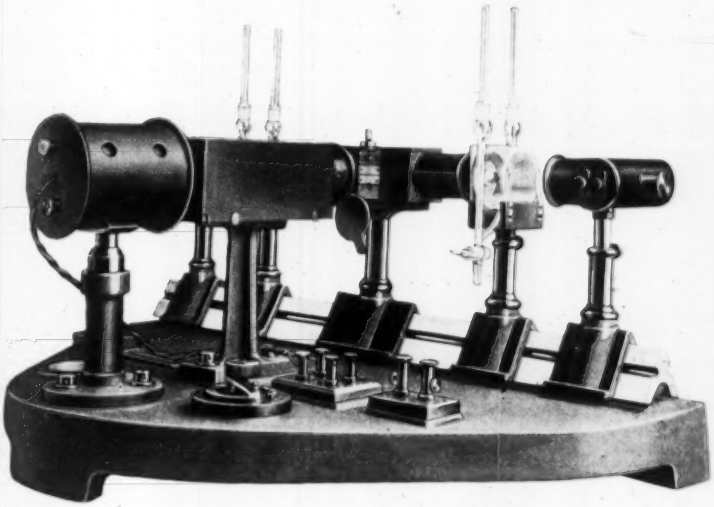


Fig 3

the galvanometer. First the slit should be closed and then slowly opened only a few hundredths of a millimetre. The use of a shunt-box in parallel with the galvanometer is recommended.

Recording Color Analyzer

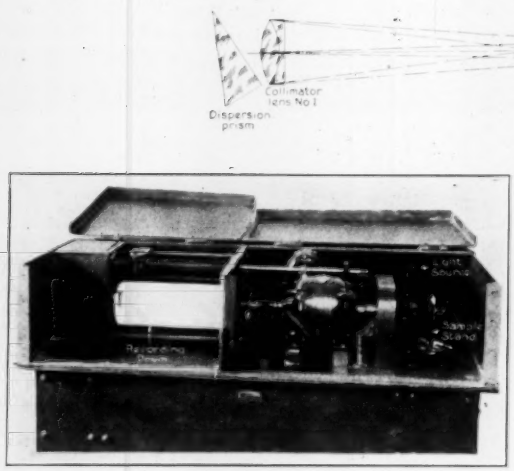
(General Electric Company)

THE color analyzer, a photoelectric device, automatically draws for permanent record the color curve of a sample in the visible spectrum. It is so constructed that either solid substances or transparent materials can be analyzed. It is a laboratory instrument, best used for the accurate control of the basic materials entering into the manufacture of colored products.

Light from a vertical, tungsten-ribbon filament passes into the slit of a dispersive system. Emerging from this system through another slit as monochromatic light, it is passed into a collimator. Here it is divided; half is taken off with a right prism and brought to a focus at a sample stand, and half passes through a shutter and is brought to focus on a flicker disc, which has on its surface a standard white pigment. Light from the sample is collected and brought to a focus in the plane of the flicker disc and is passed into a photoelectric tube.

As the flicker disc is revolved, the photoelectric tube views alternately the standard and sample at a rate of 60 alternations per second. A greater amount of light reflected from the standard than from the sample results in a pulsating photoelectric current which is amplified electrically and used to control a motor-operated shutter in the standard light path. This shutter

will operate until the beams are of equal intensities. The balance point is indicated by the recorder.



As the record drum revolves, the wave length of the light passing through the exit slit of the monochromator is varied at a uniform rate from 400 to 700 millimicrons, and the curve obtained indicates at each wave length the position of the shutter which allows an amount of light to be reflected from the standard equal to that being reflected from the specimen. The shutter is so constructed that the opening is directly proportional to the amount of light passing through.

Approximately 3½ minutes are required to obtain a characteristic curve —the period from the time when the pen starts drawing the curve until it is raised after completing the curve.

The power source for the analyzer includes 110-volt, 60-cycle alternating current to supply the power transformer and the flicker motor, and 8-volt direct current for the lamp and filament currents. It is recommended that an 8-volt, 210-ampere-hour storage battery be used.

Since the analyzer is a recording instrument, it does not require the services of an operator with specialized training in optics. As it uses a photoelectric tube, it has ample sensitivity at the violet end of the spectrum, where visual spectro-photometers must always fail because of the low visibility of violet light.

The importance of the recording color analyzer lies in its value to industry, in nearly every branch of which control of the color of products is necessary. Accurate measurement of colors is the first concern of manufacturers of fabrics, particularly in the delicate shades which often deceive the eye. Color control is also of basic importance in the making of inks, paints, dyes and paper. In fact, there is scarcely an industry without a color problem.

One of the most important fields of usefulness for the recording color analyzer is in cataloging of the curves of different dyes, so that new colors with predetermined characteristics can be obtained at any time by the proper mixture of standard dyes already at hand.

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HEAT UNITS AND COMBUSTION

Preliminary Draft of Part 9—Heat of Combustion, Instruments and Apparatus Section of the Power Test Codes of the A. S. M. E. Committee Number 19 on Instruments and Apparatus, C. F. Hirshfeld, Chairman. Mechanical Engineering, Dec. 1930, pages 1093-1095.

This Part consists of 38 "paragraphs" and the draft here published is only an abstract. No illustrations are reproduced. An introductory note states that complete copies of the preliminary draft of Part 9 may be obtained from the society's headquarters. This Part treats of calorimetric apparatus for solid, liquid and gaseous fuels, constant-volume or oxygen bomb calorimeters for solid and liquid fuels and constant-pressure or flow calorimeters for gases. It is probably the most thorough, yet condensed, engineering treatment of this important subject ever prepared in the English language. The briefest possible statement of its scope is a list of its contents, as follows: Description and Classification—Heat Units, Total and Net Heating Values; Available Calorimeters Range and Accuracy; Installation; Precautions in Taking Readings; Bomb Calorimeters for the Determination of the Heating Values of Solid and Liquid Fuels—Ordinary Method of Making a Determination for Solid Fuels, Calorimetric Determination of the Heating Value of Liquid Fuels (and) Flow Calorimeters for the Determination of the Heating Value of Gases. The same readers of INSTRUMENTS who manifested such keen interest in its Special Calorimetry Issue, Feb. 1930 will be interested in the first publication of Part 9. Almost all of it is of distinct interest to our readers, but the reviewer feels that one assertion may be singled out by reason of its significance as a comment on the state of the art and as a challenge to the American instrument industry: "An effective method of minimizing cooling-correction errors consists in accurately controlling the temperature of the calorimeter environment . . . by providing a complete water jacket the temperature of which is kept constant to 2 or 3 hundredths of a degree by means of a sensitive thermostat . . . This method is capable of a high degree of accuracy and possesses certain advantages . . . but no commercial instrument of this type is, at present, available." It is to be hoped that before Part 9, now published in Preliminary Draft form, appears in its final "approved" form, there will have been brought out on the market suitable thermostatically jacketed calorimeters meeting the requirements of the A. S. M. E. Power Test Codes so satisfactorily that they will be listed and described in the final revision of Part 9.—M. F. B.

PRESSURE

Wind Pressure on Circular Cylinders and Chimneys. H. L. Dryden & G. C. Hill. Bureau of Standards Journal of Research, Sept. 1930, pages 653-691.

In this paper a summary is given of the published model experiments on the wind pressure on cylinders and of some previously unpublished experiments made at the National Bureau of Standards on models, on a large cylinder in natural winds, and on the power plant chimney in natural winds. This information is collected and analyzed for the purpose of estimating the wind pressure on chimneys and other cylindrical structures at known wind speeds. The new experiments are in large measure determinations of the local distribution of pressure over the entire surface of the cylinder in the model experiments, and over a suitably chosen section in the experiments in natural winds. In addition, the overturning moment on a 10 by 30 foot cylinder in the natural wind was directly measured.

Piezo-Electric Indicator for High-Speed Explosion Motors (Piezoelektrischer Indicator fuer schnellaufende Verbrennungsmotoren). J. Kluge & H. E. Linckh. Zeitschrift Verein deutscher Ingenieure, June 21, 1930, pages 887-889.

After discussing the familiar indicators a new instrument is described which operates by piezo-electric pressure measurement, that is, the forces to be measured act on a quartz crystal and produce on this crystal charges proportional to the forces. The apparatus consists of a pressure measuring chamber of steel in which 2 pieces of quartz are placed, and a tube voltmeter. The chamber is built directly into the cylinder of the motor. The greatest sensitivity of the indicator is 11 mm. deflection for one atmosphere. The range can be increased to 1000 at by addition of a condenser. The inherent frequency of the oscillograph loop is 2000 Hz, that of the chamber 100000 Hz. A few diagrams taken on a single cylinder four-stroke motor on SPS are reproduced. From the pressure-time diagram the indicated Horse-power of the motor can be simply determined. 10 references.—H. A.

Indicating of High-Speed Motors (Indizieren von schnellaufenden Motoren). Kurt Schnauffer. Zeitschrift Vereins deutscher Ingenieure, July 26, 1930, pages 1066-1067.

Describes a method for recording without distortion phenomena which change very rapidly, f. i. vibrations, pressures in explosion motors, etc. The principle is to transform the movements due to the quantities to be measured into changes of capacity which are then used in an electric oscillating circuit with self-induction and capacity. The arrangement is fully described and diagrams reproduced. One diagram shows the pressures in the cylinders of an explosion motor at 1550 rpm. 3 references.—H. A.

Equipment for Measuring the Rolling Pressure. (Vorrichtung zur Druckmessung au Walzwerken). E. Voigt & W. Lueg. Mitteilungen Kaiser Wilhelm Institut fuer Wisenforschung, Vol. 12, Report 154 (1930) pages 161-164; Stahl und Eisen, Oct. 8, 1930, pages 1442-1443.

The authors designed a simple instrument to measure the rolling pressure in rolling mills. An elastic measuring box, filled with mercury is deformed by the rolling pressure, thus displacing the mercury into an attached tube of small cross-section. This tube is provided with contact points which are connected with electric bulbs. The course of the rolling pressure can also be registered. Rolling pressure curves were taken in cold rolling soft steel. The instrument is well fit for supervising the rolling process.—G. N.

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SPEED, ACCELERATION, TIME

Automobile-Engine Acceleration. Clarence S. Bruce. S. A. E. Journal, Sept. 1930, pages 274-278-319. Includes Discussion.

Marking the completion of the investigation of engine acceleration in connection with a study of the economic volatility of motor fuels that has been under way since 1920, the paper is in the nature of a final progress-report and presents a summary of the results obtained. The earlier work done is reviewed briefly, following which the phase of the work that the paper covers, comparisons of fuel performance with downdraft and updraft induction-systems and with three separate carburetors connected by short pipes to the three intake ports of the engine, is described. Although the latter arrangement roughly represents cold carburetion, complete parallelism with the other series of tests is not possible since the three carbureters were not equipped with accelerating-charge pumps. The effect of the accelerating-charge pump was brought out in the discussion, a car so equipped traveling 160 ft. in 6 sec., while other cars of the same make but not fitted with the pump required 0.2 sec. more. Another point raised was the influence on acceleration exerted by the character of the interior surface of the manifolds. In reply, the author said that this factor had a great effect.

Development of a Recording Accelerometer. Bernard J. Strouse and J. Canfield Marsh. Engineers and Engineering, May 1930, page 109.

This paper, which was awarded first prize in a competition of student members of the American Society of Mechanical Engineers, Philadelphia Section, describes the development and use of an accelerometer that will measure the performance characteristics of an automobile while accelerating through the gearshift range. The development of the apparatus, the procedure for test runs and the calibration and interpretation of results are discussed fully with the aid of numerous diagrams. The authors conclude from their study that (a) it is entirely feasible to measure directly the acceleration of a car through the gearshifts; (b) the short-period pendulum-type of indicator has proved to be most suitable for this purpose, because it is simple and self-contained, responds quickly, records continuously, and works well on any ordinarily level street; and (c) records obtained with this type of indicator reveal, directly and conveniently, the most interesting performance characteristics of an automobile.

The Stroboscopic Vernier-Method (Ueber das stroboskopische Noniusverfahren). H. E. Linsk & R. Vieweg. Elektrotechnische Zeitschrift, June 5, 1930, page 817.

An arrangement of 3 stroboscopic discs of one is driven by the motor of unknown speed the second (in the middle) by a synchronous motor, and the third is stationary and serves as vernier. Usually 49 radial slots are arranged around the circumference.—H. A.

Introduction of the Conception "Half-Oscillation" for Time-Meters (Einfuehrung des Begriffes 'Halbschwingung" bei Zeitmessern). Elektrotechnische Zeitschrift, Oct. 30, 1930, page 1530.

In order to eliminate the contradiction met with in measuring time against all other branches of measuring oscillations the Gesellschaft fuer Zeitmesskunde und Uhrentechnik has adopted the expression half-oscillation for the time a pendulum goes from one to the other side, and oscillation for the full time from the starting point to the return there, just as f. i. for the full period of an electric oscillation.—H. A.

The Evaluation of Coasting-Measurements by the Time-Differential Line (Die Auswertung von Auslaufmessungen durch die Teilzeitlinie). J. Wicher. Elektrotechnische Zeitschrift, Oct. 9, 1930, pages 1426-1431.

Losses, friction, and mass of machines is most frequently determined by taking the speed curve over time after the machine has been cut off from its supply and letting it run until it comes to a stop. In this method the drawing of the tangent to the curve is required which, however, is possible with only slight accuracy. The author develops a new method which shall obviate this drawback he does not plot the speed curve over time actually elapsed but over the time intervals between the individual readings made in taking the speed curve. Several examples illustrate the method which gives a greater accuracy in the higher speed ranges, while in the lower (near coming to rest) the old method is the more accurate one.—H. A.

Measurement of the Period of Oscillation of a Clydonograph by Means of Surge Waves of Known Period (Messung der Eigenzeit eines Klydonographen mittels Wanderwellen von bekannter Zeitdauer). Elektrotechnische Zeitschrift, May 8, 1930, pages 676-679.

The period of oscillation of a clydonograph is determined according to a method of Sommer by surge waves of definite length of time. The error due to the gradient in the wave front is eliminated by calculation of the wave front; the equations give the course of the wave as a function of only two constants K and T depending on the characteristics of the circuit. With these 2 constants amplitude and steepness of any surge wave can be determined. The period of the tested instrument was measured to 40 x 10^{-8} seconds for positive and 63 x 10^{-8} seconds for negative polarity. 13 references.—H. A.

A Review of the Use of Kerr Cells for the Measurement of Time Intervals and the Production of Flashes of Light. J. W. Beams. Review of Scientific Instruments, Dec. 1930, pages 780-790.

Indispensable to research workers in the fields of measurement of time intervals of the order of a millionth down to several billionths of a second—not only by reason of the thoroughness and scholarship displayed in this lengthy article, but because of the 38 references comprising about twice that many separate bibliographical items. The development of Kerr cells and of their applications is traced from the discovery of the Kerr electroscopic effect in 1875, which furnished a means of operating a "light shutter" which responds almost instantaneously to electrical control. Four diagrams of elementary and elaborate set-ups are given, together with descriptions and critical discussions. Tables of Kerr constants, and of dispersion in the Kerr effect (wave lengths 4400 to 6600 A. U.; carbon disulphide and nitrobenzol as media) are included. Reference is also made to recent progress in the purification of nitrobenzol which in spite of its large Kerr constant is unsuitable as commercially obtainable.—M. F. B.

X-RAY TESTING & EXAMINATION

Cellulose as It Is Completely Revealed by X-Rays. George L. Clark. Industrial & Engineering Chemistry, May 1930, pages 476-487.

Presented before the Division of Industrial and Engineering Chemistry at the Atlanta Meeting of the American Chemical Society April 1930. Great improvements in X-ray technic as used in the study of cellulose are outlined.—M. E. H.

Efficiency of Production of X-Rays. Warren W. Nicholas. Bureau of Standards, Journal of Research, October 1930, pages 843-865.

A complete description of the intensities obtainable outside X-ray tubes for a wide range of practical conditions are obtained.

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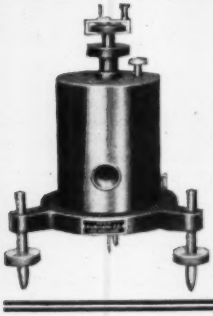

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M. F. BÉHAR, INSTRUMENTS, Vol. 4, No. 3, March 1931, pages 143-172, 46 figs.

Third instalment of Chapter XI of Handbook of Industrial Instruments. It includes the following sections:

9. Properties of Springs and Diaphragms.
10. Bourdon, Spiral and Helical Tube-spring Gages.
11. Diaphragm and Bellows Gages.
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16. Miscellaneous Industrial Features and Accessories.

INSTRUMENT SPRINGS AND DIAPHRAGMS

The Status of Knowledge of Their Elastic and Endurance Properties

M. F. BÉHAR, INSTRUMENTS, Vol. 4, No. 3, March 1931, pages 173-181.

Compilation of published data on "fatigue," drift, hysteresis, temperature modulus of coefficient of elasticity, etc. and abstract of privately communicated paper on damping properties and "dynamic ductility."

MEASUREMENT OF AIR FLOW

E. OWER, INSTRUMENTS, Vol. 4, No. 3, March 1931, pages 182-192, 6 figs.

This instalment continues the discussion of the vane anemometer. It considers mechanical friction, effect of variations of air density, optimum balde angle.

WORKING VISCOSITY

H. L. HAZELTINE, INSTRUMENTS, Vol. 4, No. 3, March 1931, pages 193-194, 1 fig.

This is the fourth of a series of articles on varnish testing.

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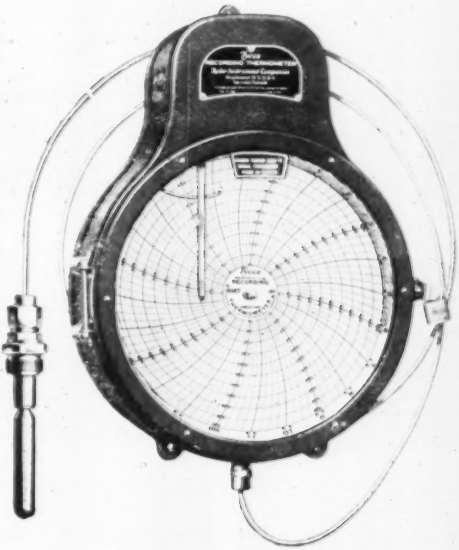

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